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AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

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VOL. L.
JUNE, 1903.

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NEW YORK:
PUBLISHED BY THE SOCIETY.

1903.

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TRANSACTIONS.

Paper No. 942.

VIRTUAL GRADES FOR FREIGHT TRAINS.*

By A. C. Dennis, M. Am. Soc. C. E.

With Discussion by Messrs. B. S. Randolph, S. Maximoff, John A. Fulton, C. D. Purdon, F. H. Hebblethwaite, William G. Raymond and A. C. Dennis.

It is well known to railway operating men that a run at a hill, especially a short one, is a great help toward getting the train over it. The tonnage rating for heavy freights, over probably every road in America, is greater than the load that can be started at certain points. The engineering departments of our railways know, in a general way, that momentum is of some help, but few have attempted to take advantage of it when fixing grades, or have investigated to what limits it could be used.

During the past year more than 3 000 miles were run by the writer, with a dynamometer, on heavy freight trains loaded much beyond the rating for the ruling grade, to see what minor grades could be run with momentum, and where the stalling point was on those which could not be run.

The dynamometer record was condensed and plotted on profile paper above the grade and alignment; speed, pull, grade, and curvature being thus shown, so that the train resistance could be readily taken from the pull of the locomotive and compensated for change of speed or velocity head, grade and curvature.

* Presented at the meeting of December 3d, 1902.

The train resistance, in pounds per ton, compensated for change in velocity head, grade and curvature, was plotted for very many points and speeds for each train, and the mean of these points taken, as nearly as possible, for each train.

Fig. 1 shows what is believed to be the correct resistance under the conditions given, and differs radically from the results obtained by Wellington and other authorities experimenting with light trains, cars and rails.

The experiments indicate that the resistances which increase with speed balance very nearly the decreasing journal friction for trains of box cars of 2 000 tons or more, the tare of which is one-third of the gross weight on a solid frozen roadbed. The resistance for such a train is about 4.7 lbs. per ton for speeds from 7 to 35 miles per hour. Warm weather and a less rigid roadbed modify this, somewhat, reducing the resistances at low speed and increasing them at high speed, but the difference is so slight that the 4.7 lbs. has been used as a constant. The resistance due to cold varies from enough to skid the wheels, it is said, to practically nothing after the train has been run fast for some time.

The resistances after the train has stood for some time are about 2 lbs. per ton above the normal until the train has been run enough to get the journals well lubricated and warmed.

The resistances seem to be greater than normal when increasing the speed and less when decreasing, after compensating fully for the change of velocity head. A train increasing its speed from 10 to 20 miles per hour, and maintaining it, would pull appreciably harder than if just reduced to 20 miles an hour from a higher speed. From coasting tests, with the locomotive shut off, it appears that the resistances per ton for the locomotive were about the same as for empty cars, or about 9.0 lbs. per ton.

As train resistances vary with the loading, it was necessary to adopt a common basis, or "Rating Ton," as the unit for comparing trains. The unit adopted, called the rating ton, is the ton of loading in a box car, or the tare weight reduced to its equivalent in resistance to a ton of load.

The train resistance for a rating ton, for speeds from 7 to 35 miles, is practically constant at 2.6 lbs. per ton. To reduce tare to rating tons for 0.4% ruling grade, for example, the following method is

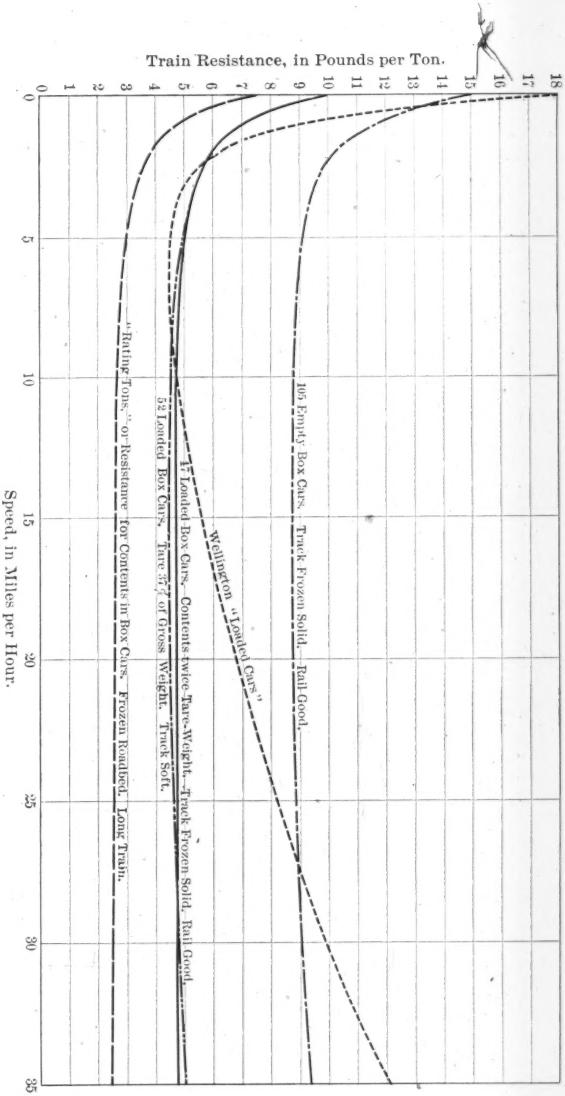

TRAIN RESISTANCE CURVES FOR HEAVY FREIGHTS.
Train Resistance, in Pounds per Ton.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
0
5
10
15
20
25
30
35
Speed, in Miles per Hour.
105 Empty Box Cars. Track Frozen Solid. Rail Good.
Wellington "Loaded Cars."
17 Loaded Box Cars. Contents twice Tare-Weight. Track Frozen Solid. Rail Good.
53 Loaded Box Cars. Tare 33% of Gross Weight. Track Soft.
"Rating Tons," or Resistance for Contents in Box Cars. Frozen Roadbed. Long Train.

Fig. 1.

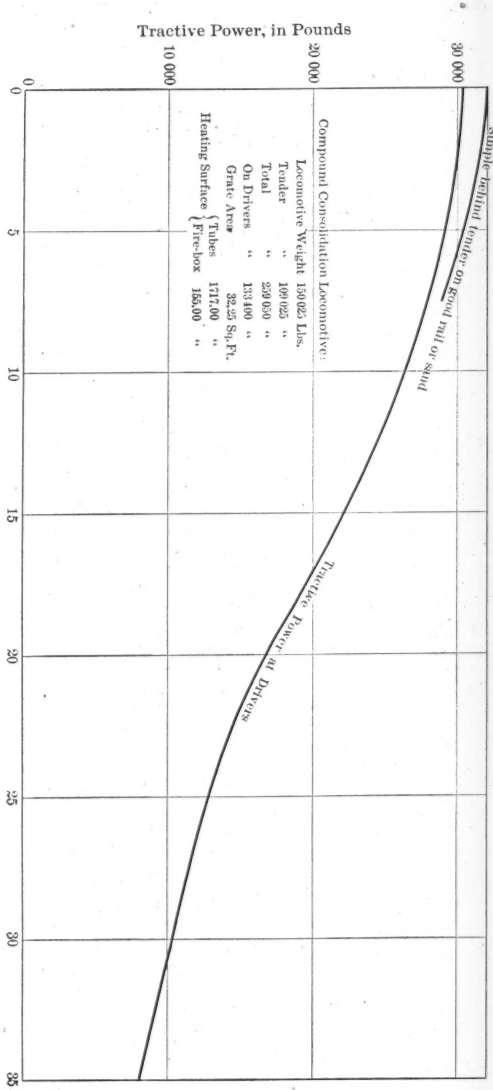
used: The train resistance for the rating ton is 2.6 lbs., and the gravity 8.0 lbs.; or, 10.6 lbs. per ton, total resistance. A ton of tare has 9.0 lbs. train and 8.0 lbs. gravity resistance, or 17.0 lbs. total, which is 160% of the rating ton. Similarly, to change tare into rating tons, multiply by 160%, 151%, 144%, 139%, 134%, 131% and 128%, respectively, for the rating-ton equivalent on 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0% grades.

Fig. 2 shows the tractive power at the drivers, for a consolidation locomotive, as actually performed. The locomotive was a Pittsburg Compound. The weights were as follows:

Pony truck		16 625 lbs.
Drivers	32 875 lbs.	
	32 125 "	
	36 175 "	
	32 225 "	
On drivers		133 400 "
Locomotive		150 025 "
Tender		109 025 "
Grate area		32.25 sq. ft.
Heating surface of tubes		1 717 "
" " " fire-box		155 "

The working pressure was 200 lbs., which is sufficient to slip the drivers on good rail, up to 8 miles per hour, or higher. The boiler capacity was sufficient to keep a steam supply for all ordinary work. The curve of tractive power was obtained by adding to the dynamometer pull at any point the grade and rolling resistance of the locomotive and tender. The points of trial selected were those where the locomotive should have been working near the maximum, and covered a large range of speeds and many repetitions at the same speed. These results have been plotted, and the curve shown is what is thought to be a fair average. In general, this curve lies about 1 000 lbs. below the irregular maximum.

After the locomotive has been worked to the maximum for about a mile there is a considerable drop in power, due to failing steam pressure, so that the velocity grade curve of the next tenth higher grade (Figs. 3, 4 and 5) will give results more nearly corresponding to the actual performance of the locomotive after passing the first mile



LOCOMOTIVE TRACTIVE POWER CURVE.

FIG. 2.

when working on a grade in excess of that for which the locomotive is loaded.

The rating for this locomotive, in rating tons at 7 miles per hour on a 0.4% grade, is equal to the tractive power at the drivers for that speed (28 200 lbs.), divided by the resistance per ton (8.0 lbs. gravity + 2.6 lbs. train) $= \frac{28\,200}{10.6} = 2\,660$ gross tons for the total train. The gross train less the locomotive and tender (130 tons actual × 160% = 208 rating tons) = 2 660 — 208 = 2 452 rating tons behind the tender. For a train loaded with two contents to one tare, for every 3 tons there are 2 tons contents, which equals 2 rating tons, and 1 ton of tare equals 1.60 rating tons; the equivalent load, then, for the 2 452 rating tons is $\frac{3}{2 + 1.60} \times 2\,452 = 2\,046$ actual tons behind the tender loaded two contents to one tare. The rating for all tare $= \frac{2\,452}{1.60} = 1\,529$ tons. The rating for 25 miles per hour on a 0.4% grade $= \frac{12\,750}{10.6} = 1\,203$ gross rating tons; and 1 203 gross, less 208 locomotive and tender, = 955 rating tons behind the tender = 803 tons of train loaded with two contents to one tare, or 597 tons all tare.

The tractive power divided by the gross "Rating Tonnage" gives the pounds per ton of power. From this take the train and gravity resistance, in pounds per ton, and the remainder will be the force for acceleration if plus, and for retardation if minus. This remainder, reduced to its grade equivalent, at 2 lbs., = 0.1% grade, and divided into the difference in velocity heads for two speeds, will give the distance necessary for that change of speed. The speeds for each change of one mile per hour should be taken separately and the sum taken, if it is desired to calculate the distance accurately.

A table was calculated and curves plotted from it showing the performance of the locomotive on various grades and at various speeds on the basis of the above-determined train resistances and engine power: Figs. 3, 4 and 5 for 0.4%, 0.5% and 0.6% grades, respectively.

The distance ordinate for any particular grade rate shows the distance necessary to run from 0 or 30 miles per hour, as the case may be, in order to attain the corresponding speed; and, inversely, the speed attained or lost between two distant ordinates. As an example: On the 0.4% diagram, suppose a start to be made on a level grade 5 000 ft. long, followed by 4 000 ft. of 0.6% grade, fol-

0.4%

DIAGRAM SHOWING DISTANCES FOR VARIOUS CHANGES IN VELOCITY ON GRADES SHOWN, FOR CONSOLIDATION LOCOMOTIVE WORKING COMPOUND AND HAULING FULL RATING FOR 0.4% GRADE, COMPENSATED.

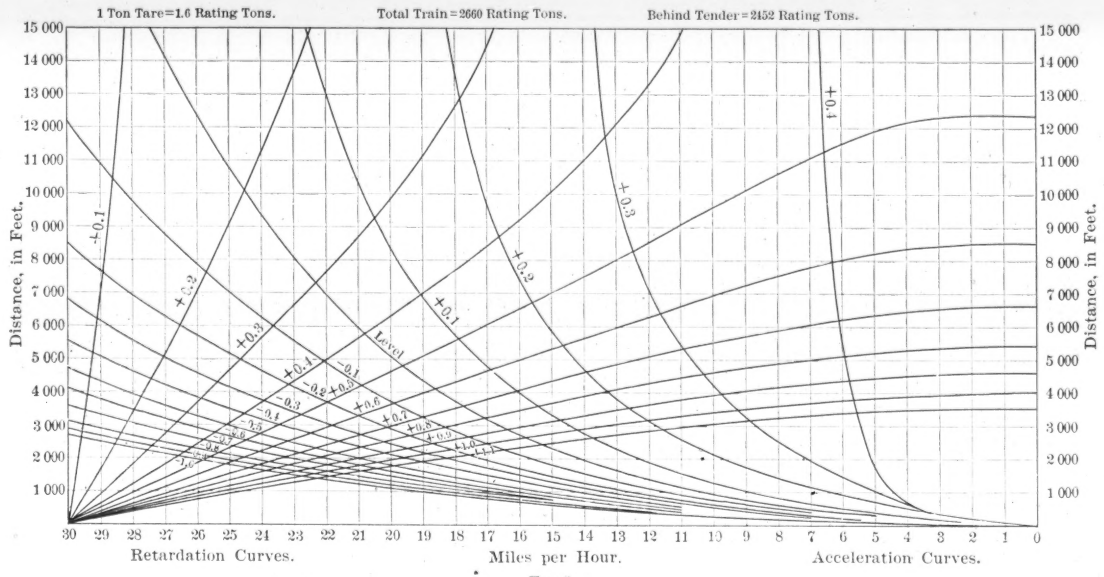


FIG. 3.

0.5%

DIAGRAM SHOWING DISTANCES FOR VARIOUS CHANGES IN VELOCITY ON GRADES SHOWN, FOR CONSOLIDATION LOCOMOTIVE WORKING COMPOUND AND HAULING FULL RATING FOR 0.5% GRADE, COMPENSATED.

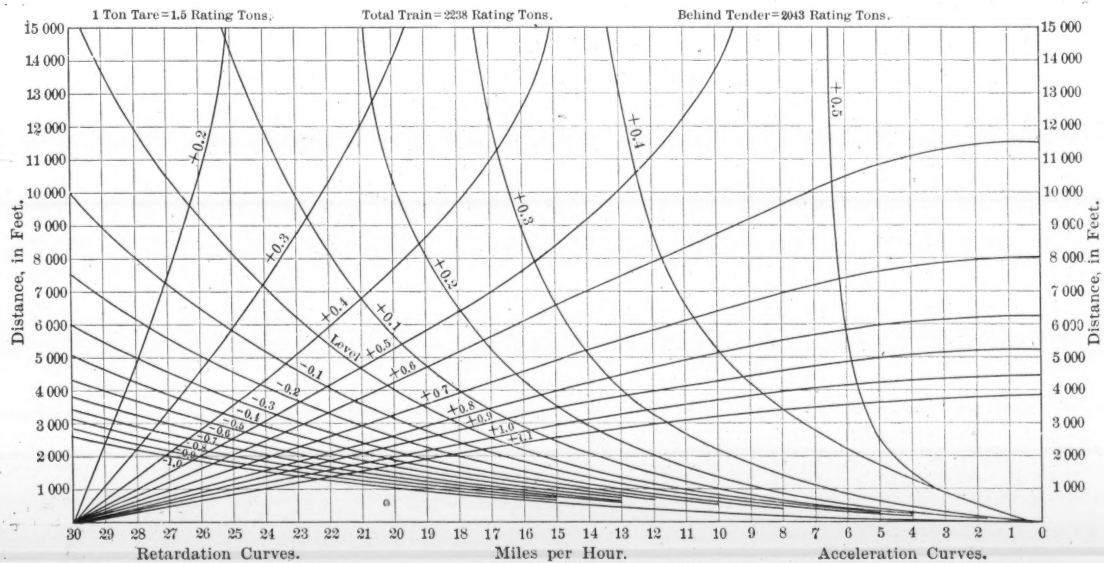


FIG. 4.

0.6%

DIAGRAM SHOWING DISTANCES FOR VARIOUS CHANGES IN VELOCITY ON GRADES SHOWN FOR CONSOLIDATION LOCOMOTIVE WORKING COMPOUND AND HAULING FULL RATING FOR 0.6% GRADE, COMPENSATED

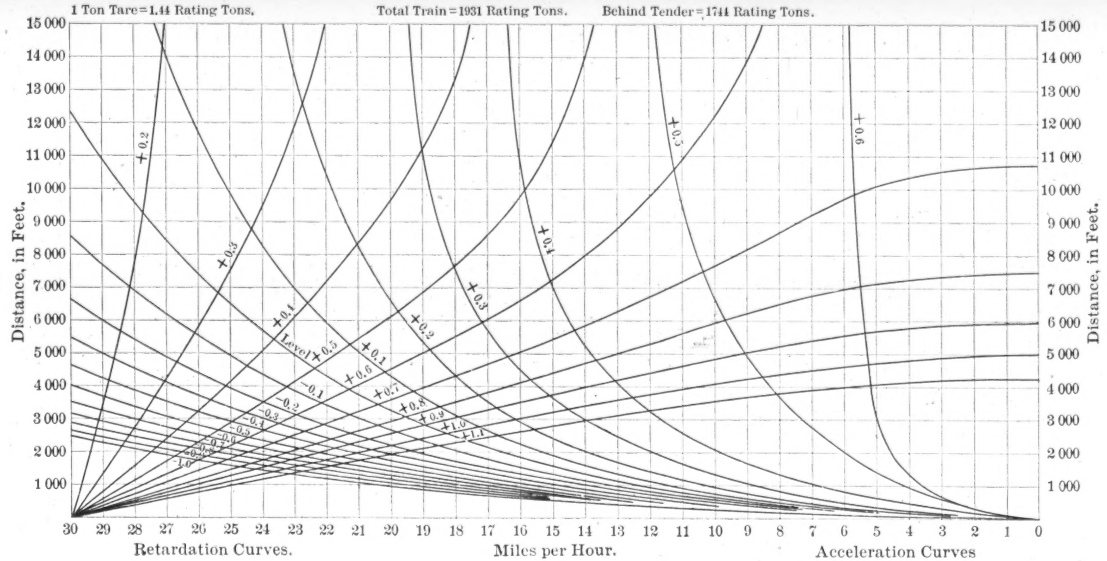


FIG. 5.

lowed by 3 000 ft. of — 0.2% grade. The speed ordinate corresponding to 5 000 ft. on a level grade is 20 miles per hour; 20 miles per hour on a 0.6% grade corresponds to a distance of 3 600 ft., being the distance required for speed reduction from 30 to 20 miles per hour; 4 000 ft. more distance on the 0.6% grade, or 7 600 ft., corresponds to 9½ miles per hour, the speed at the top of the 0.6% grade; 9½ miles per hour on the — 0.2% grade corresponds to a distance of 500 ft.; 3 000 ft. more distance on the — 0.2% grade, or 3 500 ft., corresponds to 21½ miles per hour, the speed at the foot of this — 0.2% grade.

Some experiments were made with a ten-wheel locomotive of large boiler power and big drivers, with the hope that this type would be better suited to operate momentum grades because of its higher efficiency at high speeds, but the results were rather disappointing, as stops have to be figured on at each station. The ten-wheel locomotive holds speed better, but attains it less readily, and, in general, when running for an adverse grade from rest, reaches the foot of the grade at less speed than the Consolidation, but holds it better, stalling at about the same place.

The railway engineer's almost universal disapproval of momentum grades is probably caused by the lack of an easily-worked method of defining the limits for their proper use, and the mistaken idea that their introduction will cause stalling from bad weather conditions or from the power being in bad condition. These adverse conditions apply with greater force to long, ruling grades than to the shorter, steeper momentum grades, as adhesion and steaming power are taxed more, or taxed longer, on the former grade, if the momentum grades are not the ruling grades under favorable conditions. In momentum grades part of the work is done by momentum, which is not affected by weather conditions.

Whether or not the engineers who locate railways figure on momentum, the operating officials take advantage of it to pull what they are able, regardless of the rate of grade. One division which the writer studied had 0.5% east-bound and 1.0% west-bound grades—these grades being very fairly arranged to balance the heavier east-bound traffic—but because of the length of grade with stops, and uncompensated curvature on the 0.5% profile grade east-bound, the highest possible rating was that for 0.77%, while, by means of momentum, the shorter 1.0% grade west-bound could be operated with exactly the same rating as the east-bound.

Grades out of a divisional point should be reduced to a somewhat lower grade than at other points, as the first few miles a train is run after standing for some time show a very much higher resistance than the normal, especially in cold weather. The writer knows of one case, in extremely cold weather and high wind, but with pretty clean rails, when it was impossible to start a train out of a level, crooked yard with the locomotive unassisted, but the same locomotive, an hour afterward, handled this train on a 0.4% grade as usual.

For ordinary stops, at least 0.1% compensation is advisable, although a compound locomotive can generally start anywhere that it can be run through without losing speed, but at greater risk of broken draft rigging and loss of time, to avoid which generally justifies a slacking of the ruling grade.

On favorable divisions, the rating can be raised 50%, for about 10% of the original construction cost, by the proper introduction of momentum grades, and, incidentally, the rise and fall and curvature be improved. These improvements may often postpone indefinitely the necessity for double track, and are in line with, as well as being a preliminary to, double-tracking. Because of fewer stops, momentum grades generally tax locomotive powers less on double-track lines.

DISCUSSION.

Mr. Randolph. B. S. RANDOLPH, M. Am. Soc. C. E. (by letter).—There is another factor affecting the question of "momentum grades," which Mr. Dennis does not appear to have mentioned: This consists in the surplus energy stored in the boiler after a level or down-hill run, where the use of steam has been for some time less than the boiler production.

No locomotive has yet been built which can supply steam for an indefinite period as fast as it can be used in the cylinders, even at an economical speed; but, by virtue of this stored energy, when the steam is at full boiler pressure, a locomotive can haul a much greater load than can be hauled continuously. In ascending a long grade, a point will be reached beyond which the possible load will depend entirely on the capacity of the boiler to produce steam for current use.

The distance of this point from the foot of the grade will be a function of the momentum and this stored energy.

For all grades having a length less than this distance it would be possible, therefore, to increase the rate, and, by making a corresponding decrease in the length, not affect the maximum load. Attention is called to a practical application of this in Mr. Dennis' paper.

To any engineer of experience in the location of railways, numerous examples will occur where such an arrangement will result in no small saving in construction costs.

Some years ago, when connected with railway construction, the writer began the collection of data bearing on this subject, with the view of developing some facts of practical value. Subsequent engagements in an entirely different direction prevented further work on this line, but it has always seemed to be a field for investigation of no small value in the economic construction of railways. This paper would appear to furnish valuable data for such a study.

Mr. Maximoff. S. MAXIMOFF,* Esq.—The subject to which attention is called by Mr. Dennis' paper is very interesting indeed; and yet it is true that it has never been discussed sufficiently.

As questions of the same kind are arising in Russia from time to time, the speaker's intention is to give some general idea as to what is being done there, as far as he is able to do so, not being in possession of exact figures.

Fixing grades is one of the most delicate operations in the problem of location of railroads, and, practically, it has to be revised every time that the increase in traffic makes it necessary to undertake further developments. It is not doubted that the proper location of momentum grades would greatly improve existing conditions, and this should always be considered in the first installation.

* Engineer of Ways of Communication, St. Petersburg, Russia.

Mr. Maximoff.

The speaker does not know whether railway engineers really disapprove of momentum grades. He believes, on the contrary, that they always introduce them when the possibility of reducing the first cost of installation is clear; but in some cases their adoption involves an extra expenditure in construction, and one should be certain that the traffic will be large enough to justify it.

In some cases the difficulty of introducing momentum grades reaches the impossible. The location of bridges and other railway constructions is often unchangeable; and the necessity for protecting the line from snow exercises a very peculiar influence on the profile of the road. Shallow excavations are regarded as the most dangerous in this respect, and, in Russia, the recent practice in such cases has been to make the excavation like an embankment; which means, that the excavation on one side of the track is deepened considerably and enlarged, and the roadbed looks somewhat higher than other parts of the excavation, as on the new lines of the Moscow-Riazan-Kazan Railroad, for example.

Sometimes, also, a curved transition in vertical plane from one grade to another is used, which is also favorably reported as modifying the shock in the angle.

The difference of level between two divisional points can generally be varied only within small limits, and the author himself thinks that the grades out of a divisional point should be reduced to a somewhat lower grade than at other points.

Now, the grades, curvatures and other technical features of every new railroad in Russia must be approved by the Government; that is what is called the "technical conditions" and is always printed.

The same is required for every further development, and the sets of technical conditions furnish the most valuable material for the study of the history and present state of railway engineering in Russia.

In flat country the steepest grades only exceptionally exceed 1%, and one of the oldest and best equipped roads, namely, the Vladikavkas Railway, found it advantageous to rebuild its main line, while reducing the highest grade to 0.6%, at an expense of some $15 000 000.

The distance between the stations very seldom exceeds 20 miles, for the purpose of providing water supply for the locomotives; and, after some years, it is invariably reduced by opening intermediate stop and crossing points; and, usually, level grades, or grades not exceeding 0.2%, for further location of stations, are provided within every 5 to 10 miles, of course, on a sufficient length of track.

Even in the distance of 5 miles there is good reason to take care of momentum grades, but frequent stops change very substantially the conditions of riding, and the stations occupy a very large percentage of the whole length of the line.

Add, too, that the organization of movement of trains on Russian railroads differs very materially from the practice in this country.

Mr. Maximoff.

The freight trains are not always composed of the full number of cars, and their later arrival is regarded as less important, if it does not disturb the movement of passenger trains.

The largest number of cars now admitted in one train is nearly seventy empty cars, and the length of the main track varies between 2 000 and 2 300 ft. on small crossing stations. Thus the desire to increase the number of cars in the train involves an extra expenditure on the stations, and increases the difficulty of handling, maintaining and inspecting them. On the other hand, it is practically restricted by the strength of coupling accommodations.

The number of cars at the disposal of each railroad in Russia, Government or private, is regulated by the Government according to the demands of the daily traffic, and every car can be run on every track of the Empire, except on a few railways of small gauge.

The commercial side of this mutual exchange is regulated by reasonable laws. That state of things has great advantages, and the troubles on the grain-carrying railroads of the South of Russia were diminished considerably after its adoption; but it has also some inconveniences, because all substantial improvements of the rolling stock must be undertaken almost simultaneously.

In a very few cases the introduction of momentum grades would lead to increasing the speed at the foot of those grades, and thus necessitate the adoption of heavier types of rails, thus involving additional expense or a great variety of types of rails.

Another unfavorable circumstance is that the elevation of the rails on curves is always adapted to quick-moving passenger trains, and the wheels of the cars of a heavy freight train, by want of centrifugal force, are pressed against the interior rail, thus increasing the resistance. In the technical conditions it is mentioned that the resistance of a train moving on a grade on a curve must be the same as on the highest grade without curvature; that means that in curvature the grades must be reduced; but it is very difficult to ascertain whether in practice this rule is followed carefully, and, even if the passenger trains move under good conditions, the freight trains may be somewhat neglected in such respect.

Thus, many different circumstances, *pro* and *contra*, fight the introduction of momentum grades, and, in fact, all their theoretical advantages may be destroyed by some intractability on the part of the engineering *personnel*, or may become of minor importance in the presence of other urgent improvements of a commercial nature; but still the speaker fully agrees with the author that the lack of good experiments leads to lack of attention to this subject.

In Russia the calculation of virtual grades is generally made by using the formula of General Petroff, whose remarkable studies on the friction and on the resistance of trains are printed in Russian and

French, and are thus accessible to American engineers. Further developments are necessary, however. Mr. Maximoff.

To make good experiments is a difficult task; and great faults are often committed by very able men, especially in the determination of the grade, which always needs the most precise leveling.

During construction the grades are often executed by the contractors, and not exactly in accordance with the drawings. Even in the maintenance of the railroad, considerable changes may occur by the renewal of ballast. For example, the speaker once was told that a certain station, after some few years of existence, instead of being on a level grade, was found to be on a 0.3% grade. If the greatest precautions for an exact determination of the grade be not taken, the results of experiments may become entirely wrong.

The conditions of the roadbed, whether frozen or not, that is, whether more or less elastic, are also to be examined carefully, and the latest practice is to use the photographic method of observation, as developed by Mr. Vassiontynski, Engineer of Ways of Communication.

For eliminating, as far as possible, the influence of the personal ability of the engineer of the train, the apparatus of Mr. Livtsnak was found of great value, showing to the locomotive man the profile of the line, the position of the engine, and its speed at every moment.

Russian rolling stock is somewhat different from American, and the author's conclusions cannot be adapted entirely to the peculiar Russian conditions.

The subject is of great interest and of considerable importance, and is treated very successfully by the author.

JOHN A. FULTON, M. Am. Soc. C. E. (by letter).—The writer has made some experiments to find out what speeds a specific freight train ought to be able to make, on various rates of grade, with the ultimate object of determining to what extent it is practicable to use momentum grades. Mr. Fulton.

One of the conclusions he arrived at, and which might, perhaps, have been accepted beforehand, is, that every rate of grade has its corresponding normal speed for any specific train, and that every speed has its normal grade for that train.

A train which can maintain a uniform speed of 15 miles per hour on a long + 0.70% grade can maintain a uniform speed of 40 miles per hour on a — 0.20% grade; and if at any moment that train is actually running at a speed of 40 miles per hour, it is virtually running down hill, although the profile grade at that point may be very decidedly up hill.

Another conclusion arrived at is, that momentum already acquired has but a limited field of influence, and cannot be spread out indefinitely over a long, steep grade.

A train running from *A* to *B*, 5 or 6 miles distant, starting from a

Mr. Fulton. state of rest at A, and working steam continuously, will have substantially the same speed at B as if it had left A with a high speed, of, say, 40 miles per hour.

The writer's diagram, Fig. 6, for a + 0.40% ruling grade, is based on the assumption that the combination of engine and train will be such that it can maintain continuously a speed of 10 miles per hour on a + 0.40% grade of unlimited length.

This is a somewhat lighter load, assuming the same engine for each, than one which could make only 7 miles per hour on a + 0.40% grade, which the author has assumed.

On comparing the performances of the train, as indicated by the author's diagram, with those of the lighter train, by the writer's diagram, it will be seen that this lighter train does not acquire quite as high speeds in a given distance, and loses speed more quickly on an adverse grade.

These differences are generally slight, but, in some cases, as on a + 0.10% grade and with an initial speed of 30 miles per hour, the resulting speed at the end of one mile of such + 0.10% grade would be 29 miles per hour, according to the author's diagram, while, according to the writer's diagram, this engine hauling a lighter train would have a speed of only 25 miles per hour.

On comparing the author's and the writer's diagrams, for + 0.50% and + 0.60% ruling grades, similar differences appear.

It may be said, therefore, that the writer's diagrams, adapted best to engines having about 56 in. drivers, give results a little more conservative than those of the author.

The author notes a considerable drop in steam power after passing the first mile, indicating that his train is too heavy even for the 7-mile continuous speed on a + 0.40% grade, and that the apparent differences between the results on the two diagrams are not quite as great as the actual differences.

It is probable that these differences are largely due to the widely different values ascribed to train resistance.

It seems incredible that train resistance can be substantially a constant quantity for all freight-train speeds.

If that were true, then a freight train, having an initial speed of, say, 40 miles per hour when commencing the descent of a — 0.30% grade (the author's 4.7 lbs. per ton is the equivalent of a + 0.23% grade), would continue to increase in speed indefinitely, and would "run away" even with steam shut off.

According to the writer's method, this train, adapted, as noted, for a + 0.40% ruling grade, would slow down to about 36 miles per hour even when working steam to the best advantage; and, if not working steam, but running by gravity alone, it would slow down to 16 miles per hour, for the reason that the train resistance at this latter speed would be about 6 lbs. per ton, or equivalent to a + 0.30% grade.

Mr. Fulton.

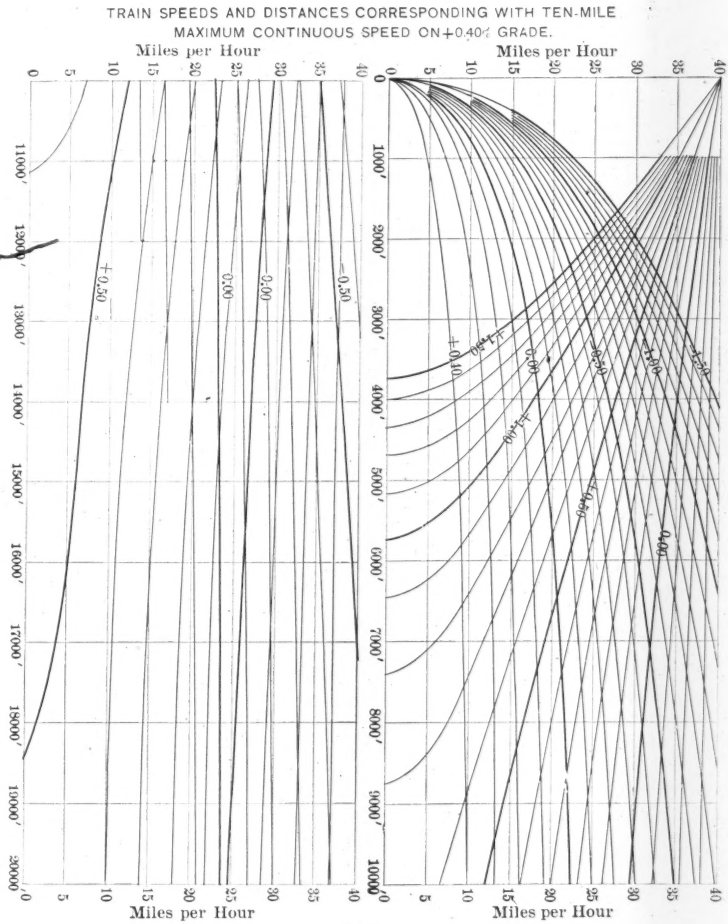


FIG. 6.

Mr. Fulton. Mr. Wellington's experiments in "coasting" down a —0.70% grade coincide almost exactly with the values determined from the *Engineering News*' formula for train resistance ($R = 2 + \frac{V}{4}$); and it seems probable that this formula is close enough for all practical purposes.

The method of using the diagram will be understood from the sketch, Fig. 7, and may be described as follows:

Select the initial speed on the curved line representing the grade in question; follow that curve a distance equal to the grade length, and read the speed at that point; with that speed on the curve representing the next grade follow along that curve, as on the former curve, and read the speed as before.

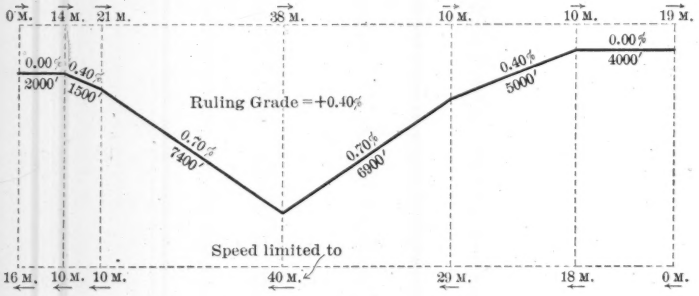


FIG. 7.

The sketch, Fig. 7, shows how it is sometimes possible to build a piece of railroad on apparent 0.70% ruling grades, and then operate it as on 0.40% ruling grades.

Mr. Purdon. C. D. PURDON, M. Am. Soc. C. E. (by letter).—This question has been considered more or less by nearly all the Western roads, in the last few years, in connection with improvements of gradients.

It is well known that the momentum of a train does assist in climbing adverse grades, and the only objection that the writer has heard made by engineers is that, in case of a train getting stalled at the foot of a grade, it would not be possible to start again with the maximum load; and for this reason some engineers advocate that in reducing grades they should always be reduced to the new maximum, regardless of their length. If this were done, however, the operating department would, no doubt, find out in a short time what maximum load could be operated over the reduced grades, and would undoubtedly use that load; so that it would seem advisable in grade reductions to take account of the momentum. This, however, the writer would only advocate in connection with the reduction of grades on an existing road.

VELOCITY HEAD AND TRAIN

FOR A TRAIN HAVING A MAXIMUM SPEED OF 12 MILES PER

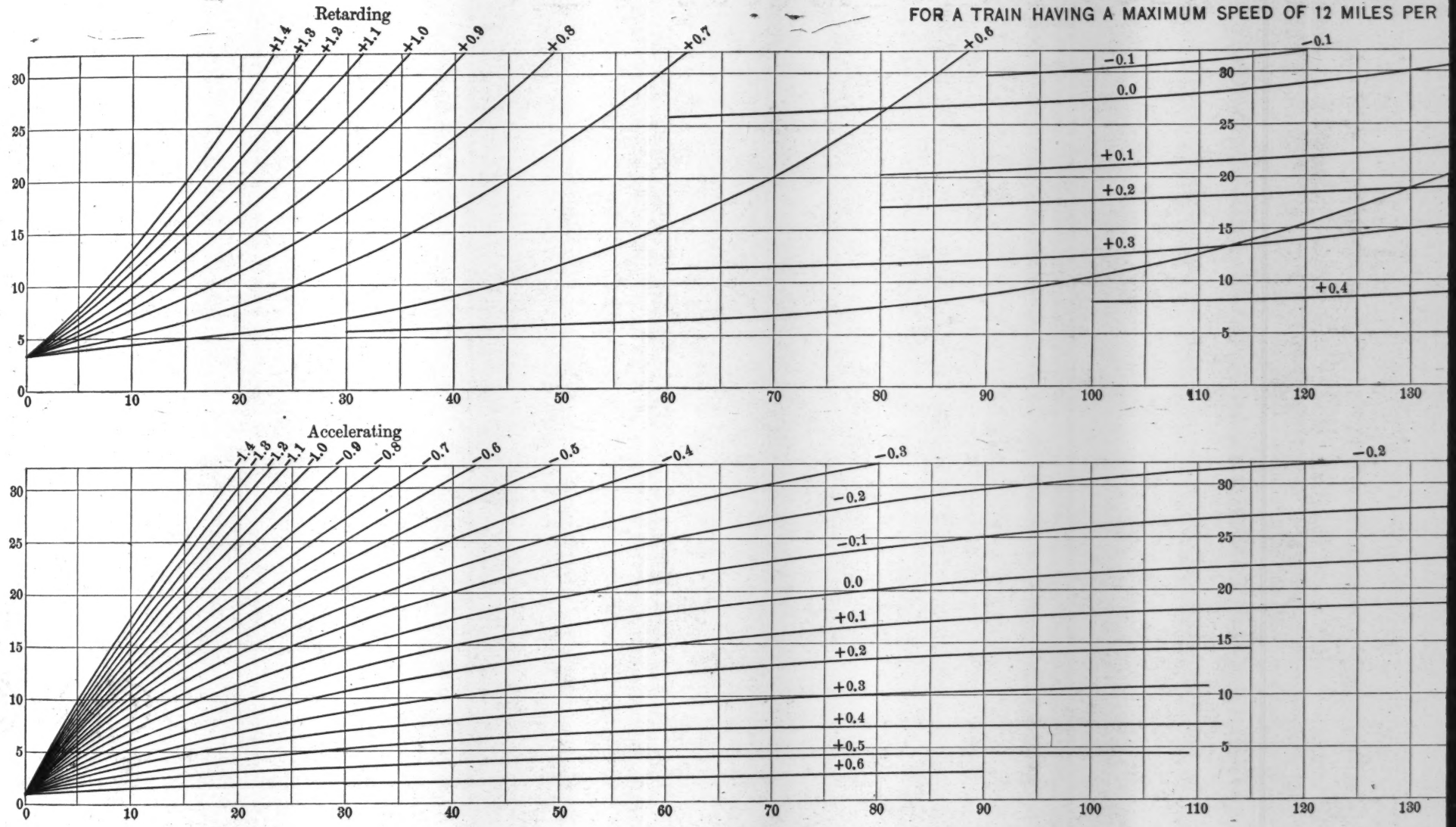
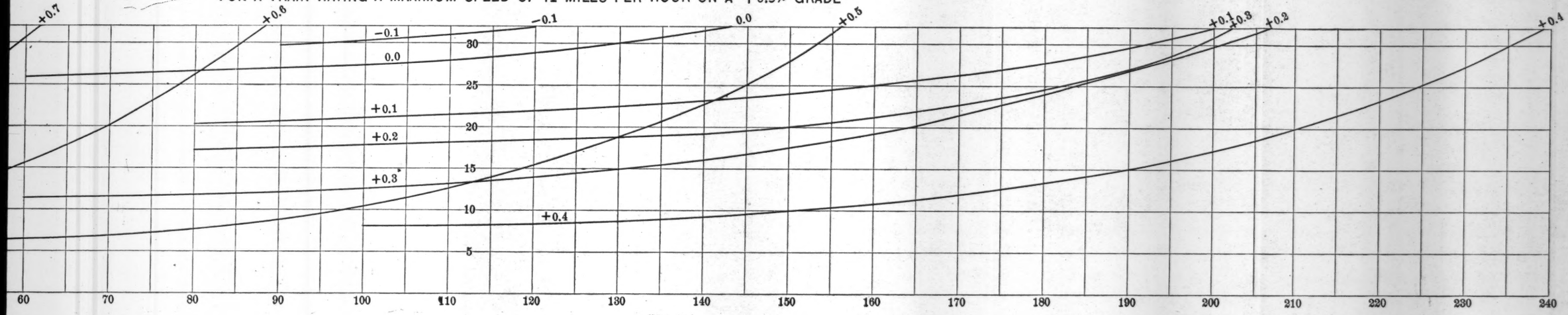
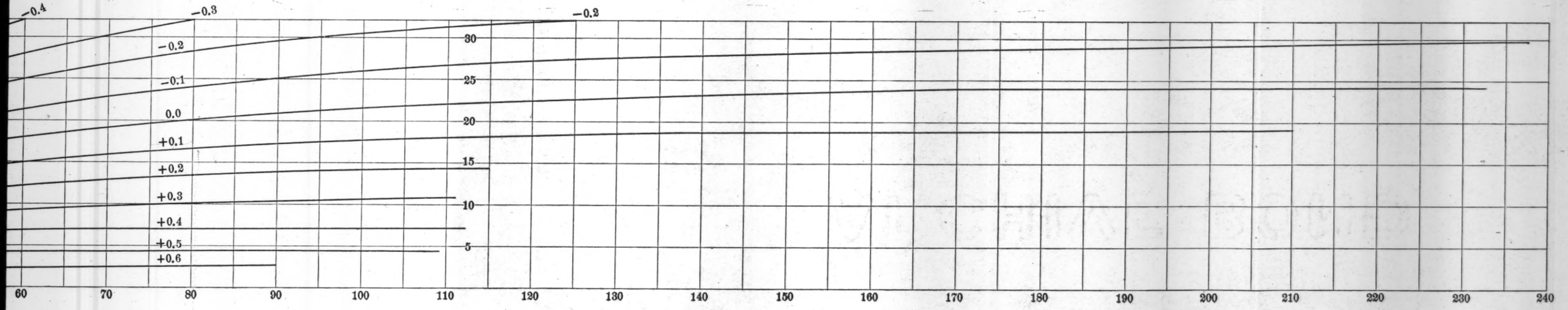


PLATE I.
TRANS. AM. SOC. CIV. ENGRS.
VOL. L, No. 942.
PURDON ON VIRTUAL GRADES.

VELOCITY HEAD AND TRAIN SPEED

FOR A TRAIN HAVING A MAXIMUM SPEED OF 12 MILES PER HOUR ON A +0.5% GRADE





Mr. Purdon.

In building a new road he would not exceed the maximum grade adopted in any case, as the principle of momentum afterward applied would simply make the new road so much the better, besides which, on a well-established road the stations have already been settled, and the stopping points for trains, at stations, water-tanks, etc., have been established, so that the momentum can be calculated with considerable accuracy. On a new road, all these points will come up later, and if momentum grades were established on a new road, the introduction of a water-tank or a new station, or some other reason, might destroy all calculations.

The writer does not consider the author's diagrams as the most convenient for the purpose, and submits herewith two diagrams, Plate I, such as he uses. These take no account of the speed of the train, but use the velocity head, which, of course, is interchangeable with the speed. These particular diagrams are calculated for a train that can maintain a speed of 12 miles per hour on a rising grade of 0.5 per cent. The accelerating grades start with a velocity head of 0.88, equal to 5 miles per hour, and, after a stop at a station, the distance required to gain this velocity is taken as the starting point on the accelerating grade.

The upper diagram shows the retarding grades, and stops at 3.55, equal to a speed of 12 miles per hour, so that by taking any velocity head required by the upper diagram the distance on any adverse grade which would be run by a train before the speed would fall to 12 miles per hour can be ascertained. The diagrams are calculated in substantially the same manner as those by Mr. Dennis,* but, in making the calculations, the rating diagram of the Southern Pacific Railroad was used, which gives varying train resistance on account of speed from 4.8 lbs. per ton at ten miles per hour to 20½ lbs. per ton at 46 miles per hour. It is noticed that this does not agree with Mr. Dennis' paper, as he states that the train resistance is nearly the same for speeds between 7 and 35 miles per hour. At stations, of course, the grade should be somewhat lighter for a short distance on each side, to enable a train with a maximum load to start; and, in ascertaining the momentum, it should be calculated as if the train stopped at each station.

Mr. Hebblethwaite.

F. H. HEBBLETHWAITE, Assoc. M. Inst. C. E.—In the year 1900 the speaker was engaged at the Naval Yard Extension Works, in Hong Kong, in laying out a yard for the manufacture of concrete blocks. The concrete was machine-mixed at one end of the yard, run down grade on trestles, in cars of 18-in. gauge, and dumped into moulds, the empty cars being pushed back by hand. A loaded car weighed 4 000 lbs., an empty car 500 lbs.

The speaker would like to ask the author how he would determine

* In a paper published in *Engineering News*, November 22d, 1900.

Mr. Hebblethwaite.

the grade down which the loaded cars could be pushed with exactly the same expenditure of power as would be requisite to push the empty cars up; in fine, the grade to be laid out so that a man could as easily push an empty car up as a loaded car down. There must be such a grade. How can it be determined?

Mr. Raymond.

WILLIAM G. RAYMOND, M. Am. Soc. C. E. (by letter).—The writer supposes that the late A. M. Wellington, M. Am. Soc. C. E., was the first railroad engineer to discuss at all adequately the problem of momentum or velocity grades, and, for a number of years after the appearance of his discussion, comparatively little attention was paid to the subject; but, for the past five or ten years, railroad engineers all over the country have been somewhat carefully studying and experimenting with such grades, and there have appeared in print, in the technical press and society proceedings, a very considerable number of discussions, both purely theoretical and as the result of extended experiments.

But while engineers are figuring theoretically the gains to be secured by the consideration of momentum or velocity grades, and while the western roads have, in many instances, laid out such grades and operated them with apparent success and economy, we are met by the manager of the busy eastern road with the statement that on his road he does not dare to start out a train the engine of which is loaded with a load greater than that with which it can start from a state of rest on the steepest *de facto* grade over which it is to pass.

The writer himself, from time to time, has taken part in discussions of momentum grades, and has devised formulas for the lengths of such grades for given locomotives and resistances, and has discussed at some length the most economic speed of freight trains and the principles which should govern in the design of locomotives for operation on divisions of varying characteristics; and while he thoroughly believes that considerable economy may result from a consideration of momentum or velocity grades, in the cost of original construction, in the revision of gradients on existing roads, and in the designs of motive power and its operation; nevertheless, he can well understand that on a busy road the cost of a single unexpected stop, due to too close figuring on the possibility of momentum grades, may equal or exceed the gain resulting from such considerations for a considerable period of time during which there is no such accidental stop.

The writer believes that the subject is one of considerable importance because of the possible economies involved, and thinks that a fairly complete knowledge of the prevailing practice in this matter would be of very considerable value and interest, and, therefore, he suggests the advisability of securing the opinions of operating managers on this subject, and a statement of any experiences that such managers may have had in the consideration of momentum or

velocity grades. He thinks that it might be wise to invite formally such expressions from officers responsible for the operation of both eastern and western railroads. These officers may include chiefs of motive power, general superintendents, general managers and chief engineers, according to the duties and responsibilities assigned to these different officers on the different roads. Mr. Raymond.

A. C. DENNIS, M. Am. Soc. C. E. (by letter).—The writer fully agrees with the conclusions in the first part of Mr. Fulton's discussion on virtual grades, and was equally skeptical in regard to the approximate constancy of train resistance, until convinced by a long series of experiments. He knows from experiment that a train of about 2 100 tons, with 20% empties, picked up speed from 29.5 to 30 miles per hour, with the locomotive shut off, in running 2.5 miles on a 0.26% grade. The writer suspects that a long train of all loads would exceed 40 miles per hour on a 0.3% grade with the locomotive shut off, provided the train had been running at high speed, but lacks sufficient information regarding resistances at such speed to be able to state definitely. A train of all empties will lose speed in coasting, even on a 0.4% grade, whatever the speed when starting to coast. It is impracticable to compare the resistance of two trains without knowing the proportion of tare weight, or reducing all actual tonnage to rating tonnage. Mr. Dennis.

The "boiler momentum," to which Mr. Randolph refers, will probably explain the difference between Mr. Fulton's speed and distance diagram and that of the writer.

The writer's locomotive tractive power curve for high speeds is much above the capacity of the locomotive to produce indefinitely, but not above that produced temporarily in making runs at grades. The available stored energy is roughly equivalent to 2 lbs. per ton of train, or to 0.1% of grade.

If Mr. Fulton did not consider the extra temporary boiler power, but calculated his locomotive power as strictly limited by the steam-generating capacity, his diagram should show the same results, for any rate of grade, as the writer's does for the next tenth higher. Comparing Mr. Fulton's diagram with the next tenth higher corresponding grade on the writer's diagram shows a very gratifying correspondence until a mile is covered, or low speed reached, where the two diagrams are practically the same, as the boiler momentum has then ceased to influence the writer's diagram. As before noted, after passing the first mile, on a grade where the locomotive is worked hard at a speed exceeding ten miles per hour, the grade line on the writer's diagram does not hold, but the true results are approximated by following from this point parallel to the curve of the next tenth lower grade rate. The boiler momentum, though not capable of being calculated exactly, should be considered, and has been rather undervalued by the writer, as trains acquire more speed and hold it better

Mr. Dennis. when running for momentum grade than is indicated by the writer's diagram, except for long hills, where the diagram falls short, as noted.

The problem of momentum grades contains so many personal, mechanical, and other variables, that an approximate solution only is possible. A close approximation only is necessary, as trains are not loaded ordinarily to the last ton possible, because they cannot make the required time; so a little too much momentum grade introduced will not cause stalling, and if not as much as was possible were used, some returns are obtained, for the extra construction expense, in the running time saved.

The custom, on eastern railways, of sticking to an assumed maximum grade rate, regardless of cost, stations or speed possibilities, gives a line of higher first cost and generally of a lower operating value, because of the high ruling grade at stations. Momentum grades, based on the assumption that the locomotive exerts the same tractive power at all speeds, will lead to serious error. Somewhere between these extremes is the proper use of momentum, where the greatest liberty is taken with the grade rate to make it fit the ground, limited only by the ability to join with proper vertical curves and the capacity of the locomotive plus momentum to make the required speed. Engineers who look on the percentage of rate of grade as the end and object of a railway have mistaken the measure for the thing itself. A grade should be limited, not to a maximum rate; but to the locomotive power and momentum, then made to fit the ground. The mere rate of grade is irrelevant and often misleading.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 943.

AN ALTERNATIVE LINE FOR THE NICARAGUA CANAL; AND A PROPOSED NEW METHOD OF DAM CONSTRUCTION.*

By J. Francis Le Baron, M. Am. Soc. C. E.

With Discussion by Messrs. Alfred Noble, P. C. Hains, Edward P. North, L. M. Haupt, Theodore Paschke and J. Francis Le Baron.

1.—An Alternative Line for the Nicaragua Canal.

The importance of good harbors for the termini of the Nicaragua Canal is so great that we could well afford to sacrifice several less favorable features to secure them.

On the Pacific side, Brito seems to be the only available terminus, and a harbor will have to be constructed there.

On the Atlantic side, however, there is more choice; but, strange to say, only one location for the harbor has been proposed. This appears all the more strange when the fact is considered that Greytown Harbor was ruined nearly forty years ago by the sand drift from the east, and the whole bight of the coast in which Greytown is situated is in a state of unstable equilibrium, and has been from remote geological periods. This is shown conclusively by the succession of lagoons, five in number, beginning with Silico and ending with the

* Presented at the meeting of November 19th, 1902.

present harbor lagoon, which have been formed one after the other by the westward littoral sand drift projecting itself in the form of a spit across the re-entrant coast angle and thus forming a progressive delta, which now projects fully 2 miles from the normal coast line, and which shows a growth of 9 miles into the sea, since the action began at the ancient shore line of Silico Lagoon.

The greater part of this sand, but not all, comes from the Colorado mouth of the San Juan, and is transported westward by wave action along the beach, on which the waves strike diagonally, under the influence of the prevailing easterly winds. The writer investigated this subject carefully when in Nicaragua, and discussed it in his report to the Maritime Company, in 1888.

The conditions at the mouth of the Colorado are quite different, and present a nearly stable equilibrium. Since 1865, when this whole region was surveyed by Assistant P. C. F. West, of the United States Coast Survey, there has been no appreciable change, up to the present time, at the Colorado mouth, while great changes have taken place at Greytown, as shown on the series of charts printed in the Report of the first Nicaragua Canal Board, and ably discussed by them.* The writer, however, must disagree with the able Commissioners' statement that a neutral point of equilibrium exists midway between Harbor Head and the bight where the Canal Company's canal mouth is situated. The whole geological and physical evidence of this locality points conclusively to the fact that the whole littoral, from the highlands at the mouth of the Colorado to the present canal mouth, is in a condition of constant accretion, and from the mouth of the Rio Tauro it presents a progressive curtain traveling northwestward nearly parallel to the shore line as now existing from the canal northward and northwestward, each succeeding decade removing the bight or re-entrant angle further to the northwest, which motion resembles that of an immense mole, or rather a sand wave of progression, traveling up the coast.

This view is sustained by the current observations which the writer took in the bay between Harbor Head and the canal mouth, and which, ¼ mile off shore, were found to have a direction leading directly into the bight, and normal to the coast line west of the canal.

* Page 33 *et seq.*

These facts show plainly the futility of attempting to make a harbor in this re-entrant, and the utter impossibility of restoring the Harbor of Greytown.

This action of the littoral is assisted by the detritus and trash brought down by the Lower San Juan Branch, which is constantly extending and increasing the swamp lines near its mouth, as shown by examination of the old charts, and is plainly seen by daily examinations, such as the writer made while in charge of the canal works there.

This condition was clearly understood by Major McFarland, of the United States Engineers, who examined and reported on this harbor and the canal line in 1876, and who, for this reason, advocated the location of the canal mouth to the eastward of Harbor Head, at the salient angle of the coast, where a condition of more stable equilibrium exists. The futility of building a harbor in the re-entrant angle is exemplified still further by the experience of the Maritime Canal Company.

The jetty built by them has been overwhelmed by the sands, and the channel they had cut through the littoral cordon enclosing the harbor lagoon filled up shortly after the work stopped. Since then it has opened again, on account of the action of the floods in the San Juan River, of which it now forms one of the mouths. This latter cause may preserve an intermittent channel here, but it will constantly decline in depth as the outflow of water from the rapidly shrinking Lower San Juan becomes less and less. It is the outflowing water alone that can preserve it. There is now a depth of only 6 ft. in the channel where there had been 16 ft., and a new spit is extending itself northwestward from Harbor Head to form eventually a new lagoon in front of the present one.

The Colorado mouth will now be considered. The advance of the shore line from the Highlands of the proceeding geological horizon is only 2 miles, as compared with 9 miles at Greytown, in the same time, and appears now to be about stationary. The Colorado Branch carries three-quarters of the water of the San Juan, and the lower part of the San Juan has been growing shallower from year to year, and filling up, until it has now become so shallow as to be unnavigable, and the Steamboat Company who used it on their weekly trips to the Lake have been obliged to discontinue its passage, and have built a railroad

from Greytown to near the Colorado Junction. The Colorado Branch shows a nearly uniform depth of from 24 to 30 ft. from the bar up to the mouth of the Caño Bravo, a distance of nearly 7 miles, with one stretch of from 12 to 17 ft. depth, about 1½ mile in length, and nearly ¼ mile in average width.

There are three parallel lagoons, called collectively "Agua Dulce Lagoon," on the north side, running nearly parallel to the shore line, which present the appearance of old river beds nearly at right angles to the present course of the river.

These lagoons are 4, 7½ and 8½ miles long, respectively, and each is about ¼ mile wide. They have a depth of from 12 to 24 ft.

South of the river, near the mouth and connected with it, there is an old river channel, called Simon Lagoon, having a length of 3¾ miles and an average width of ¼ mile. These lagoons and channels are all connected with the river, and furnish a harbor of 3 800 acres, besides the river itself, which is of sufficient width and depth to allow vessels to tie up to the bank on each side in the straight reaches, thus affording room, altogether, for 700 vessels of nearly 12 ft. draft, and about 20 vessels with a draft of 24 ft. Its capacity could readily be increased by a little dredging to accommodate 100. This harbor is only 1 mile from the 30-ft. sea-curve. The depth of water on the bar varies from 8 to 11 ft. at low water. The writer examined this bar in 1888, and considers it well adapted for improvement by jetties, as it consists of the same light volcanic sand as composes the beach at Greytown, and the distance out from shore to the 30-ft. curve is only about 2 500 ft.

The rise of the tide is only 15 ins. at Greytown, about 14 miles to the northwest, and would be practically the same here, and there is no inflowing current. The velocity of outflow is from 3 to 4 ft. per second, and the volume of discharge, at a low stage, is 16 000 cu. ft. per second, as measured by Major McFarland. This is likely to be increased fourfold in floods, and will never fall much below it. The depth just inside the mouth is 30 ft.

There seems to be little reason to doubt that this channel can be deepened to 24 ft., by jetties alone, especially when it is considered that now almost no water passes through the San Juanillo from the San Juan, and that the Lower San Juan is rapidly filling up and in a few years practically all the water of the San Juan will pass through the Colorado outlet, thus increasing the scouring power.

The land on the south side of the river, at the mouth, is high and sightly, and very eligible for a port, and the shape of the lagoons is such as to afford not only a most secure and land-locked harbor, but also excellent facilities for coaling and loading and unloading ships. The depth over the bar can be easily increased by dredging to the extent required after the jetties are built, or probably by dynamite alone, because, owing to the swift outflowing current and contracted channel caused by the jetties, the problem would be much simpler than that presented at Brunswick, and the depth once gained can be easily maintained by contraction works, on the plan adopted at the South Pass.

This harbor appears to the writer to be the great desideratum now lacking in the Nicaragua scheme, and he believes it can be made to fill all the requirements with but slight cost; not so much, in fact, as would be required to make a harbor at Greytown, which, in combatting all the forces of Nature, would require constant effort to keep open, while here the mighty force of the river will aid. In the one case we are fighting Nature, in the other we are aiding her.

The way by which this harbor can be made available will next be described.

The last Isthmian Canal Commission dismissed the idea of a canal on the south side of the San Juan in a few words, but these were calculated to prejudice anyone against a canal on that side, wrongfully, as it seems to the writer, inasmuch as they stated that more streams would have to be crossed on that side, stating them as follows: Frio, Poco Sol, San Carlos and Serapiqui. The Chief Engineer, in his report,* says:

"An examination of the map shows that a canal location from the Caribbean Sea to Lake Nicaragua, south of the San Juan River, would cross all of these streams. This would make its construction practically an impossibility."

Inasmuch as the plan presented by the Commission contemplates the construction of a dam at Conchudo just above the mouth of the San Carlos River and below the Frio and Poco Sol Rivers, the flooding of the river valley from this Conchudo dam to Lake Nicaragua up to the level of the lake, and the use of this part of the river for slackwater navigation, it is difficult to see how the entrance of these rivers

*Page 54.

on the south side affects the problem in any different manner than if they had happened to enter on the north side.

Really, the only streams that affect the problem are those which enter below the dam, and not above, as the canal must cross those that enter on the same side on which the canal is located.

If the canal is located on the north bank of the San Juan River, it must cross the following streams below the Conchudo dam, viz.: The Danta, San Francisco, Negro, San Juanillo (twice), and Pescado Rivers, and the Mochado, Tamborgrande, Tamborcito, Guasimo and Misterioso Creeks, making eleven crossings.

If on the south side, it would cross the San Carlos and Serapiqui Rivers and the Cureño, Tamborcito, Maria and Tigre Creeks (seven crossings); showing four in favor of the south side, but the two largest, the San Carlos and Serapiqui, are on this side. The latter is a deep stream of moderate velocity near the mouth where the canal would cross it, but it is no more difficult than the San Francisco, except in degree, it being about twice the size of that stream and subject to about the same rise in freshets, viz., 12 ft. Its crossing could be effected without difficulty by placing a lock in the canal on each side and a movable dam in the river below. The other streams, with the exception of the San Carlos, are small, and present no difficulties. The San Carlos will be merged in the lake created by damming the San Juan. The plan proposed by the writer for consideration is as follows:

To locate the canal on the south side of the San Juan River from Ochoa to the mouth of the Colorado; to build the dam at Ochoa from the north end of the San Carlos embankment hill (but not on the northeast course) to a point east of the mouth of Mochado Creek, as proposed on the old Canal Company's plan, but from the same point as proposed in that plan on the San Carlos Ridge in a direction northwest by west to the high rocky hill west of the mouth of the Mochado, allowing that creek to enter the river below the dam. All the borings taken at this locality tend to show the rock to be much nearer the surface above the dam site than below, and the geological formation indicates this; but, even if the bed-rock is as deep here as on the location adopted for the Canal Company's line, the construction of a stable and permanent dam here, the writer believes, will present no difficulty on the plan he proposes, and which he will discuss later.

Premising, then, that a dam is feasible here, this dam would raise the water in the river to 110 ft. above sea level, and the San Carlos Basin would be formed by building twenty-three small embankments on the saddles of the hills forming the San Carlos Ridge line, fourteen of which would be less than 15 ft. in height, and all with solid foundations. Ample sluices would also be built in this ridge line for the escape of the flood waters of the San Carlos, as proposed in the Canal Company's plans, and the Ochoa dam would be built as a weir to allow the escape of the flood water over the top, which plan would be perfectly safe by the method of construction herein proposed, and which will be described later.

(The United States Commission states* that there would be no difficulty in building the San Carlos embankment.)

The canal line would start, then, from the San Carlos Ridge, with a lock in both the upper and lower ridges, and would run down the valley of Cureño Creek, through Cureño Lagoon in a straight line to and across the Serapiqui River; then a curve of large radius would deflect it to the north to pass near the southern bend of the Colorado River through the bayou called Rio Blanco; thence, another curve to the left would allow a tangent to be laid passing through Colorado Lagoon direct to the Colorado River at the junction of Simon Lagoon; thence, following the river, a distance of 3¼ miles to the sea. It will be noticed (see Plate II) that the Serapiqui River is crossed in one of the bends, so that the current will be taken straight instead of broadside. By this location only four curves will be required in the canal, and these can be of as large radius as may be desired, as against twenty-one curves on the line laid down and recommended by the Commission, nine of which have a radius of only 3 280 ft., and two of 3 000 ft., while several of them are reversed curves. These numerous sharp curves are very objectionable. The chief difficulty in navigating the Suez Canal occurs on the curves, where ships of deep draft are very apt to take the ground. For this reason it would be found impracticable to operate the canal at night.

The part of the river used for the canal near the mouth is nearly straight, with no sharp curves, and the water is from 18 to 30 ft. deep. On this line there would be no cut of more than 56 ft. to the water grade, except at one or two knife ridges.

*Page 65.

The canal would be wholly in excavation from the San Carlos Ridge line to the sea, and the length from the San Carlos Basin to the 30-ft. curve in the Caribbean Sea is 44.49 miles, as against 45.15 miles by the Commissioners' line, a difference of 0.66 mile in its favor; but, as 3½ miles of the proposed line is in the Lower Colorado, where the depth varies from 18 to 30 ft., this part of it will require so little dredging that it practically reduces the length of canal in excavation to 40.49 miles, and effects a saving of 4 miles of canal to be excavated.

The flood line of the Colorado River at the point where the canal enters is only about 3 ft. above the low-water stage, so that it will be quite practical to lock into the river and use it for the lower end of the canal.

While in charge of the surveys and works of the Canal Company in 1888–89 the writer sent a party to examine and survey Cureño Creek, and another to examine the land southeast of the mouth of the Serapiqui River. In the former case the lands on both sides were reported low, with many lagoons, until the hills of the San Carlos Ridge were reached, and in the latter case the land was reported to be all wet swamp, with occasional isolated hills, for many miles in all directions. In 1887 the writer reconnoitered the San Carlos Basin. In 1888 he had the San Carlos Ridge line surveyed and personally examined it. During the same year he made a compass reconnoissance of Trinidad Creek, Manitee Lagoon, and the adjoining lands; and in 1889 he examined the Colorado River and Bar, observing that the land near the river was nearly all low and swampy. In 1888 he also sent a party to reconnoiter the land in Costa Rica south of San Francisco Island, and it reported low rolling hills, without any high land.

In 1898 the Isthmian Canal Commission caused a survey and reconnoissance to be made of Tamborcito Creek and the adjoining territory east to Manitee Lake. This examination covered Tamborcito Lagoon, and showed the character of the country to be low and swampy, with isolated hills and a few broken ridges.

These different surveys and reconnoissances practically cover the whole line, taken in connection with the observations made by the writer from the high pilot house of a steamer on the San Juan River, which failed to discover any high land on the south bank of the San Juan, until nearly up to Ochoa, except a few detached hills.

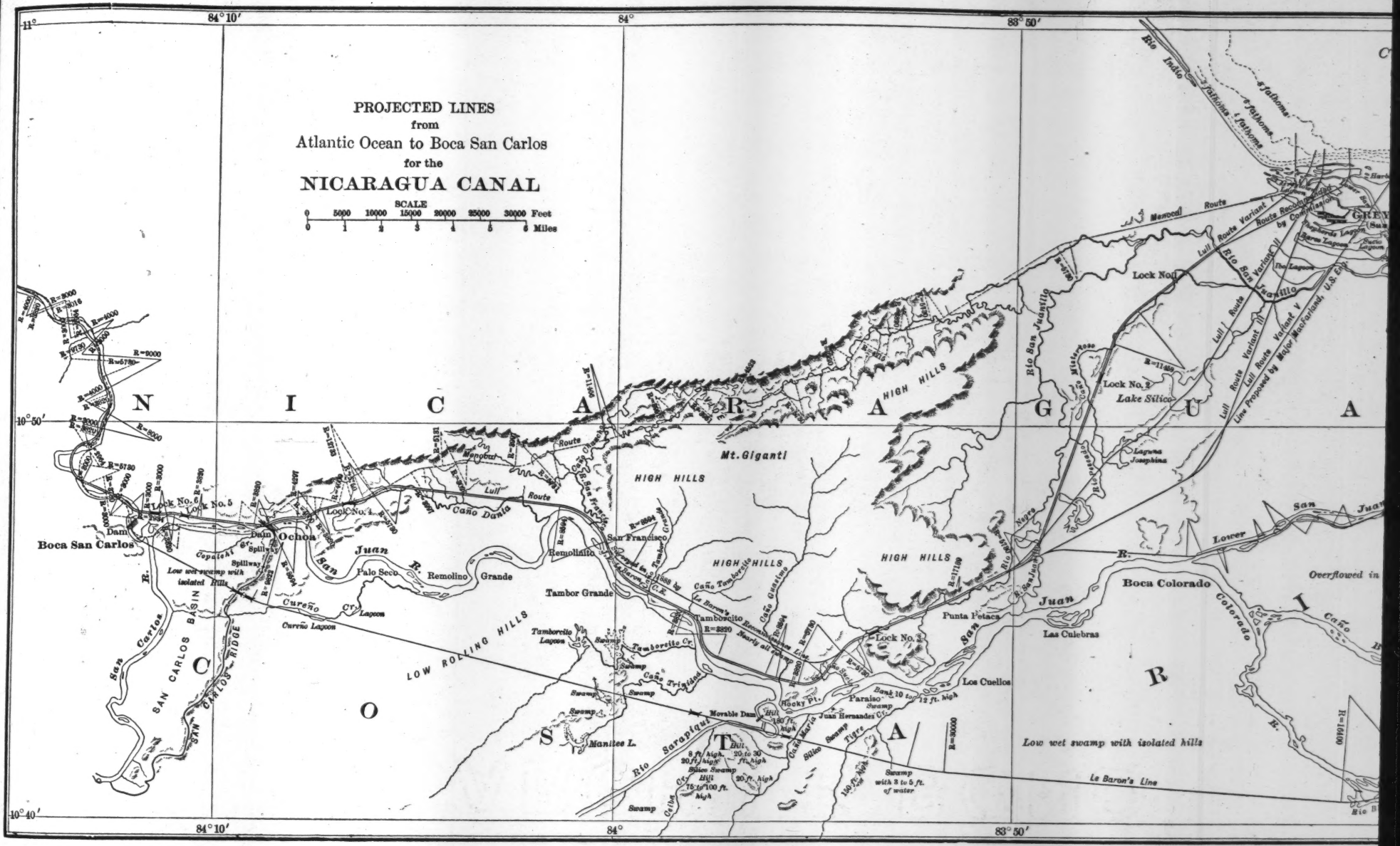
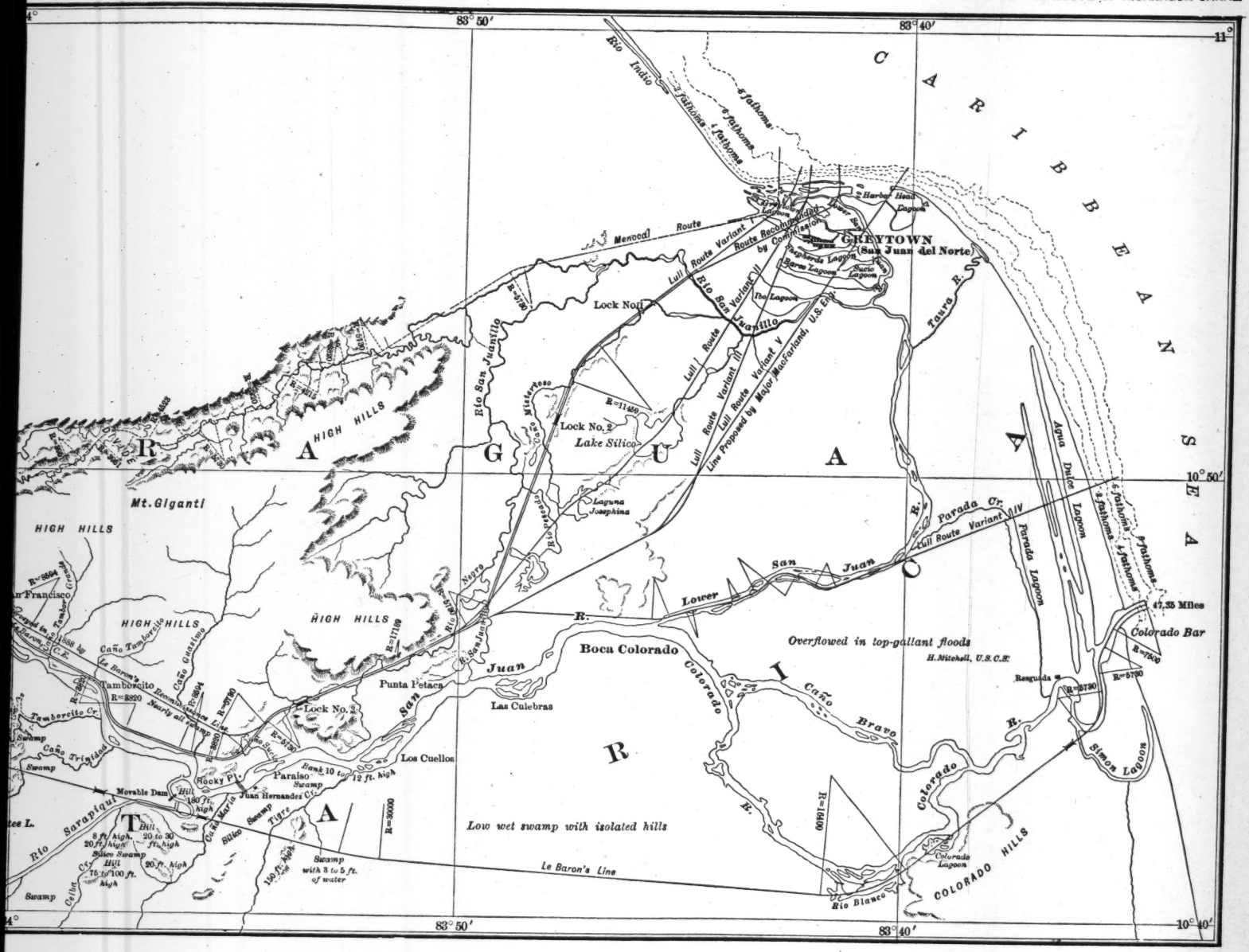

PROJECTED LINES
from
Atlantic Ocean to Boca San Carlos
for the
NICARAGUA CANAL
SCALE
0 5000 10000 15000 20000 25000 30000 Feet
0 1 2 3 4 5 6 Miles
11°
84° 10′
84°
83° 50′
10° 50′
10° 40′
N I C A R A G U A
C O S T A R I C A
Boca San Carlos
Dam
Ochoa
Lock No. 6
Lock No. 5
Lock No. 4
Lock No. 3
Lock No. 2
Lock No. 1
Spillway
Low wet swamp with isolated hills
San Juan R.
Palo Seco
Remolino
Grande
Cureño Cr.
Cureño Lagoon
San Carlos Basin
San Carlos Ridge
Mt. Giganti
HIGH HILLS
LOW ROLLING HILLS
Caño Dania
Lull Route
Route
Tambor Grande
San Francisco
Remolinito
Tamborcito
Tamborcito Lagoon
Tamborcito Cr.
Caño Trinidad
Caño Tamborcito
Caño Quebrada
Manatee L.
Movable Dam
Rio Sarapiqui
Juan Hernandez Cr.
Rocky Pt.
Paraiso
Punta Petaca
Las Culebras
Los Cuellos
Boca Colorado
Colorado R.
Lower San Juan R.
Lake Silico
Laguna Josephina
Rio San Juanillo
Rio Indio
Mexicaal Route
Lull Route Variant I
Lull Route Variant II
Lull Route Variant III
Line Proposed by Major MacFarland U.S.C.E.
Le Baron's Line
Low wet swamp with isolated hills
Swamp with 3 to 5 ft. of water
Overflowed in
Bank 10 to 12 ft. high
Hill 150 ft. high
Hill 75 to 100 ft. high
8 ft. high
20 ft. high
20 to 30 ft. high
Silico Swamp
Tigre
Celia Cr.
R=50000
R=10100

PLATE II.
TRANS. AM. SOC. CIV. ENGRS.
VOL. L, No. 943.
LE BARON ON ROUTE OF NICARAGUA CANAL.



These examinations are sufficient to justify a survey of this line, and to warrant the statement that in all probability a practical and even favorable line can be located. It is quite possible that on the actual location it may prove to be desirable to introduce one or two more curves to improve the profile and avoid high hills, but, after leaving the San Carlos Ridge line, the surface, for the most part, with the possible exception of a short stretch opposite San Francisco Island, will be found to be only a few feet higher than the bank of the San Juan River. This is absolutely known for nine-tenths of the distance to the sea. No rock has been observed on this line, and it is not believed that any large amount will be found. What there is will probably consist of medium-sized boulders. It is also possible that when the actual location is made the line can be improved considerably.

Until this line is definitely located, an accurate estimate of the cost is impracticable, but a tolerably close estimate is possible for one familiar with the country. The summit level being the same as that prepared by the Commission, there will be the same rise and number of locks, but the deep rock-cut at the mouth of the San Carlos River, and the other heavy rock-cuts at Tamborcito, Serapiqui, San Francisco and the vicinity of Silico Lagoon will be entirely eliminated, and the only heavy cuts encountered will be those at the lock sites, which are necessary in all cases.

The earth excavation will be red, white and blue clay, and swamp muck. This is predicted from the surface indications, the eroded hills, the river and creek sections along the line, and the borings taken on the San Carlos Ridge line. There will be no excavation in the San Carlos Basin, a distance of 3 miles, to give a 30-ft. navigation; and for the lower Colorado, where the line runs in the river for 3 miles, the depth of dredging required will average only 6 ft.

From the approximate estimate made by the writer, the line on the south side, herein described, can be built for about $17 000 000 less than the Commission's line on the north side.

The strong outflowing current of the Colorado is required to maintain the channel through the beach to the sea. Without this agency the canal mouth can only be kept open by constant dredging, at great yearly expense. The greater part of the discharge, however, if desired, could be turned down the Lower San Juan by constructing deflecting dikes and a barrage at the head of the Colorado.

A modification of the line herein proposed would pass into the Colorado River at the head of the Rio Blanco and continue therein to the sea. This location would only be made in the interest of economy, but is feasible by making some cut-offs and straightenings, and would reduce the cost about one-half for a distance of 12 miles.

It is contended by some that the San Carlos Basin will be filled up by sand brought down by the river. It seems to the writer that this contingency is very remote. This basin is 9 miles long and 4 miles broad, and the river enters 8 miles above the San Juan River. The average depth of the basin will be about 40 ft., and there will be about 75 to 80 ft. in the channels. When the basin is flooded, the San Carlos will enter the lake 8 miles from the canal sailing line and will deposit its load of sand as soon as it enters the still waters of the lake. It must be considered that the upper part of the river, above the basin, is rocky and contains but little sand, the river bed having been well washed, and that most of the sand now comes from the lower part, which then will be in the lake; consequently, the sand movement will be much less than it is now. Even if this basin should fill up in the course of 500 years, the canal could still be dredged through it, as in other places.

2.—Dam Proposed at Ochoa, on the Nicaragua Canal.

The writer believes that a masonry or monolithic dam would be highly objectionable, either at Panama or Nicaragua, on account of the great damage that might be done to it in a few moments by an earthquake, and which might require several years to repair, and in the meantime the canal would be closed.

Any method of construction which can be substituted, which will be free from this danger, and which is at the same time a safe and practical plan should be considered attentively and welcomed gladly.

The plan recommended by the Advisory Board of Consulting Engineers to the Canal Company was for a loose-rock dam, 30 ft. wide on the crest and 500 ft. on the base, with up-stream slopes of 1 to 1 and down-stream slopes of 4 to 1, and a total height of 70 ft. This was increased by the First United States Canal Commission to 950 ft. on the base, up-stream slope 1 to 1, down-stream slope 10 to 1 at the toe, increasing to 4 to 1 at the crest, with a width of 20 ft., and this rock fill was to be backed on the up-stream side by an earth, gravel, and

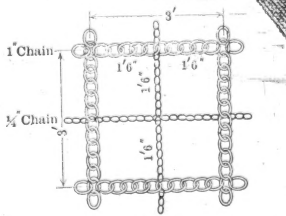


FIG. 3.

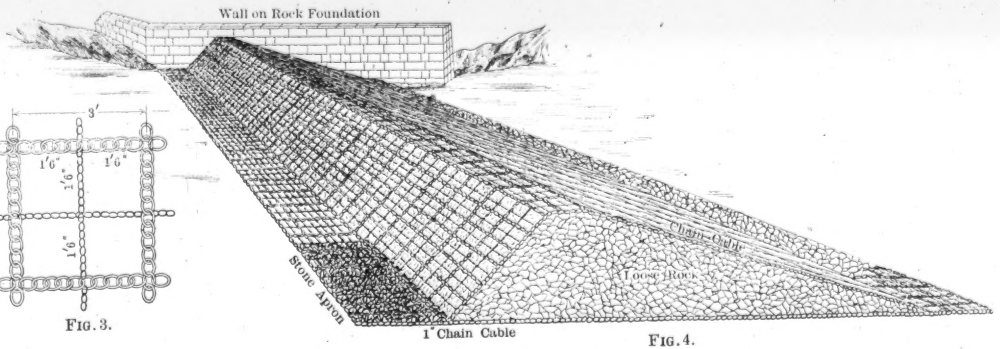
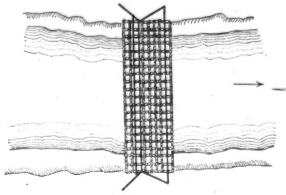
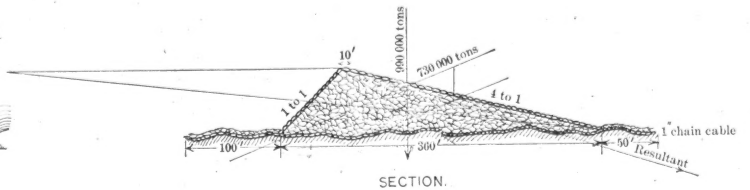


FIG. 4.



PLAN.

FIG. 1.



SECTION.

FIG. 2

chip backing, 20 ft. on the crest and having an up-stream slope of 5 to 1, with a base of 340 ft.

The writer proposes a loose-rock dam, enclosed in a heavy chain-cable net, with a base of 360 ft., a crest of 10 ft., an up-stream slope of 1 to 1, and a down-stream slope of 4 to 1, as shown in Fig. 2.

The chain composing the net would consist of 1-in. ship's cable, forming meshes 3 ft. square. These meshes would be crossed by two ¾-in. cable chains making four meshes of 18 ins. square, all to be linked together securely by split links or shackles at the crossings, as shown in Fig. 3. This net would first be laid flat on the river bottom (Fig. 1), from shore to shore, and extending up the banks to the top of the dam, and up stream and down stream above and below the dam a sufficient distance, so that, when the dam is built to its full height, the ends from the top and bottom can be brought up and fastened together on the top of the dam.

The net would also be continued on the bottom of the river, above and below the dam, as an apron, 100 ft. at each end, laid flat on the bottom of the river and covered with about 2 to 3 ft. of rock (Fig. 4). This chain net would accommodate itself to the inequalities of the bottom of the river, and would promptly sink into and fill any holes formed by scouring. As the dam settled from this cause, stone would be added on the top until a condition of stable equilibrium was secured. The chain net would give cohesiveness and stability to the structure, which would thus be made a unit. The bed should first be dredged out as deep as it could be conveniently.

To prevent the dam being broached during construction the net would be brought up on the down-stream slope from time to time to keep pace with the growth of the mound, and, being securely linked to the sides and front ends as the work progressed, would effectually prevent the degradation of the crest, no matter what depth of water was passing over.

This method of construction would present no difficulties, and the structure when completed would present no conditions that could not be readily computed. As the work progressed, sufficient broken stone and gravel would be thrown in to fill all voids of the dam, and after its completion more gravel, sand and clay would be thrown in on the upper side to make it water-tight. This material would be sucked in among the loose rocks by the current. Wing trenches in

the banks would first be excavated to rock or carried to solid masonry flanks, and these trenches filled with the chain net, and the enveloped rock would be in turn linked to the main dam.

The cost of such a dam would be far less than that of a masonry dam, and it could be built in half the time. It would be perfectly safe as a weir; an earthquake would only serve to consolidate it and fill up the voids, and it could not slide or be overturned. The rock would be that taken out of the canal prism, which would otherwise be wasted.

The First United States Commission, of which the late Gen. Ludlow was chairman, did not consider impracticable the building of a loose-rock dam at Ochoa, with the modifications that they proposed. The chief danger that they anticipated lay in broaching the crest of the dam by the deep over-rush of flood waters. This is evidently impossible when the rock is confined in a chain-cable net, with the links of the cable 1 in. in diameter. In suggesting this dam for the consideration of the Society, it is with no desire to criticize the able Commission or its engineers, but solely for the purpose of examining all sides, as would seem desirable and proper in a work of this magnitude and importance, before deciding definitely upon a route. Even in the event of the Nicaragua route being selected, it could be greatly improved, straightened and reduced in cost, between the San Francisco hills and Serapiqui Ridge, by continuing the curve a few more stations at San Francisco, and running more to the north and further from the river in a direct line to Caño Sucio (see Plate II). This would do away with three curves, two of which are reversed curves of very short radius for a canal, *i. e.*, 3 820 ft., and would substitute a tangent 6 miles long for the crooked and expensive line recommended by the Commission. It would be nearly all in swamp, and would eliminate the heaviest cut, 230 ft. in depth, on the Commissioners' line, namely, that at Tamborcito Hill. The writer knows this because he surveyed the line in 1888.

A dam of this character is not a wholly untried experiment. Many years ago the writer built a small dam similar to this, but the net was made of twine, and sand bags were substituted in place of rock, it being intended to serve a temporary purpose. In this case, for the base, a cross-trench was dug with shovels, and the dam was first built up of sand bags alone. These were washed off, however, and then the writer conceived the idea of enveloping the whole dam in a net. An

old fish net was pressed into service, and the dam was rebuilt and enveloped in it. There was no further trouble; the dam stood and resisted a pressure of about 9 ft. and a flood of 18 ins. over the crest.

Suppose the stream has a velocity of 6 ft. per second and a depth of 15 ft. over the top of the dam, conditions that probably will never be exceeded; also, suppose a mahogany log, 20 ft. in diameter and 60 ft. long, should be brought by the current end on against the dam; assume that this log would have the same velocity as the stream, viz., 6 ft. per second, and that its weight would be 942 480 lbs. ÷ 2 000 = 471 tons.

The strain of a force pressing against the center of the net would be transmitted in one-quarter ratio from link to link of the chain to the ends of the net or to some point where the net is immovably held by projecting rock or to a corner or sharp edge that holds the net immovable. The strains thus transmitted in all directions would be modified more or less by the friction of the chain net on the rocks, or by its partial fixation by sharp projections which would not prove actually immovable. The strains would also be transmitted by pressure through the rock mass of the dam to the chains on the opposite sides and ends. The amount of these transmitted strains would be modified by the solidity of the rock mass and its stability, for it is plain that if the rock mass were perfectly immovable no strains would be transmitted to the opposite chains, but, in the case of a loose rock-fill dam, the pieces of rock composing it would have a certain freedom of motion over each other, and those on the crest would be likely to be pushed over and off the crest by a sufficient force, if not withheld by the cables.

The forces tending to produce this result would be the impact and lifting force of the water applied along the whole crest of the dam, and the force produced by the impact of any large body, such as a log floating with the current. The net being divided into squares by 1-in. chains, and these again into four smaller squares, by ½-in. chains, those squares against which the moving body impinged would be called upon to sustain all the strain, provided the adjoining squares to which they were connected were held rigidly; but this not being the case, the strain would be transmitted to the next square and the next, and so on, each square resisting a certain amount in proportion to the friction of that particular square on the loose rock on which

it was lying, which friction would be greatly modified by the projecting corners of rock within each square. In other words, if the chain net were simply suspended vertically across the river, entirely free from the dam, the strains would be transmitted equally in all directions to the ends. The question then resolves itself into the friction of a heavy chain net on a rough bed of loose rock, each piece averaging, say, 100 lbs. in weight, and being more or less firmly fixed in its bed by the adjacent rocks of different sizes. In the absence of any experiments as to the amount of such friction it can only be assumed that it would increase in direct proportion to the distance from the point of application of the force. It is evident, then, that at a distance, x, from the point of application, the friction would absorb all the strains, and that part of the chain lying beyond would be unstrained. This distance would depend upon the roughness of the bed, and the amount and character of the bends in the line of strain. If this distance were short a certain proportion of the strain would be transmitted around the ends or faces of the dam, and would be taken up by the chain on those sides or ends. This would also be modified by the weight of the chain. In order to broach this dam, then, the power must be able to overcome: (1) The total weight of the chain lying on the crest and on the up-stream and down-stream sides; (2) the friction of the chain on the up-stream and down-stream sides of the dam and the crest, supposing the bottom to be immovable; (3) the tensile strength of the chain; (4) the inertia of the loose rock on the crest and as low down as the power is applied; (5) the friction of the loose rock pieces on each other; (6) the friction of each chain link on each other.

Owing to its construction, the chain would not present a rigid resistance until all the links were set up to a hard bearing. Thus it would act as a cushion and would reduce greatly the effective force of the blow. The imparting force would first have to overcome the weight of the chain and its friction on the rock and on itself to draw it taut. Therefore, if 6 ft. of water should be flowing over the dam, at a velocity of 6 ft. per second, and if a mahogany log, 20 ft. in diameter and 60 ft. long, submerged 16 ft. deep, should strike the dam, the strength of the dam would be more than double the broaching force, even after allowing the chain a working strength of only 50% of the proof test. The friction of the chain on the rock is

found by calculation to be four times greater than the whole force of the water and the log tending to overturn it; therefore the dam could not be deformed, but must remain a unit, and preserve its normal section.

Now, suppose the water to be running 15 ft. deep over the dam, and assume the mean direction of the current to be elevated 22° 30′ above the horizontal, and, disregarding the weight of the upper apron, which, however, will be firmly chained to the dam, and will exert a downward pull of 19 136 tons against any force tending to overturn the dam; then, constructing the parallelogram of forces, it is found that the resultant strikes inside the base, the ratio being 65 : 220, therefore the dam cannot be overturned; and the angle of the resultant is less than the angle of friction, therefore it cannot slide, even if it were not prevented by the earth walls of the trench in which it is embedded, and by the method of construction by which it is anchored firmly by the chains to the flanking walls.

DISCUSSION.

ALFRED NOBLE, M. Am. Soc. C. E.—The decision by Congress at its last session, favoring the Panama route, may seem to make the subject of the author's paper a dead issue. This decision, however, was subject to the express condition that the United States should be given perpetual control of the immediate vicinity of the route. This condition was wisely interposed, for the Isthmian Canal problem is no less one of sanitary than of civil engineering. If such control cannot be had at Panama and can be obtained for the Nicaragua route, it would be better to accept the latter. To attempt the building of a canal in either place without such control would be to invite the discredit and disaster which have attended previous work at Panama. Mr. Noble.

It may help to a better understanding of the paper if a brief reference be made to the principal surveys of the route.

The first survey worth mentioning was made by Colonel O. W. Childs, in 1850 to 1852, for Cornelius Vanderbilt and his associates. His project was for a canal 17 ft. deep. His report was a model as an engineering report, and has been the basis for the best of the work done since. His line followed the river from the lake to the mouth of the Serapiqui, thence by canal to Greytown. Greytown then had an excellent harbor, but, a few years later, a sand bar extended across it and it became a lagoon. The next survey, omitting other mention of the work of the United States Coast Survey in 1865 on the lower river, was made by the United States Navy in 1872–3, and is known as the Lull Survey, from the name of the officer in charge during the last year. Lull's line left the San Juan a short distance below the mouth of the San Carlos, and thence a canal was located on the left bank of the San Juan to Greytown. This passed through Silico Lagoon, and was approximately the line shown on the author's map (a reproduction mainly of the map of the Nicaragua Canal Commission) as "Lull Route Variant II." The other "Lull Variants," shown on the map were not run by Lull, were not shown on his published maps or referred to in his report, and the speaker knows no reason for thus terming them.

After the Lull survey came the series of surveys made under the direction of A. G. Menocal, M. Am. Soc. C. E., first as an officer of the United States Navy, and next as Chief Engineer of the Maritime Canal Company, the latter covering a period of about five years, ending in 1893. In these surveys Mr. Le Baron had a responsible part. The principal result of these was the development of a cut-off line, from the mouth of the San Carlos to Greytown, which had some advantages. Like many other projects in connection with this route, its difficulties developed rapidly with more detailed examination.

Mr. Noble. Since the suspension of work by the Maritime Canal Company, three examinations have been made by commissions sent out by the United States Government. As the author has fallen into some confusion with regard to these, it seems necessary to name them. The first was the Nicaragua Canal Board, whose work was done in about six months in 1895. The second was the Nicaragua Canal Commission, appointed in 1897. This commission had at its disposal about $300 000, and made more careful surveys and studies than had been accomplished previously. It completed its work and disbanded in 1899. The author has availed himself of these data, but seems to have the impression that they were the work of the third commission, the Isthmian Canal Commission, which is still in existence, in a state of suspended animation. The author's references to this commission are erroneous. The first two commissions were concerned only with the Nicaragua route. The last was charged with the broad question of Trans-Isthmian Canal communication. About $1 000 000 were placed at its disposal, and four-fifths of this sum were expended for the Nicaragua route. The United States and the Maritime Canal Company have expended a total of about $1 500 000 in surveys of the Nicaragua route, and probably two-thirds of this have been expended in the region shown on the author's map—about one-quarter of the route in length.

There was good reason for this concentration of expenditure on so short a section, for here are great difficulties and many alternatives. They are less in other sections. From Lake Nicaragua to the Pacific the route discovered and adopted by Colonel Childs has been accepted by all his successors save one. It was a satisfactory solution of the problem in that section. Of the lake section nothing need be said here. The upper river section, extending from the lake to the vicinity of the mouth of the San Carlos, some 60 or 65 miles by the river, has its best practicable solution in the building of a great dam across the San Juan River, near the mouth of that tributary, to form a so-called slack-water navigation above. The navigation thus obtained would still be somewhat hazardous on account of the numerous curves and occasional strong currents, but the tributaries above the San Carlos bring in little sediment; and a channel, once made, could be easily maintained.

The real problems of the Nicaragua route are the regulation of lake level, and the location, construction and maintenance of the section from the mouth of the San Carlos to the sea; they will be referred to in inverse order.

Below the proposed site of the San Juan dam the tributaries on the left bank of the San Juan are small. The largest, the San Francisco, drains an area of perhaps 65 sq. miles, and has a maximum discharge of possibly 4 000 cu. ft. per second. The other streams are smaller. On the opposite side of the San Juan the divide is about 50

Mr. Noble.

miles distant, and is a lofty range of mountains with volcanic peaks rising to 12 000 ft. Commencing with the San Carlos and going eastward and southward, all the streams flowing down the slopes of these mountains carry sand. The San Carlos, the largest tributary of the San Juan, has a maximum discharge of probably 100 000 cu. ft. per second. It transforms the channel of the San Juan from a stable one to a mass of shifting sand bars. The Costa Rican volcanoes have been known to erupt vast quantities of sand, and are supposed to be the main source of the supply brought down by the San Carlos and other streams.

About 23 miles below the mouth of the San Carlos the San Juan receives through its right bank its next largest tributary, the Serapiqui. This stream has an estimated maximum discharge of about 60 000 cu. ft. per second. Like the San Carlos, it drains the northern slopes of the Costa Rican volcanoes; and, again, like that stream, it is a great sand bearer. The author proposes to dam the Serapiqui. So far as known, no great pool could be formed to stop the moving sand at a safe distance from the canal. To maintain the full depth of the canal at the crossing would be at best an expensive undertaking. If no pool of magnitude could be formed the maximum discharge would have to pass over waste-ways. These would be works of great magnitude, second only to those required in the neighborhood of the mouth of the San Carlos. These considerations have been generally considered fatal to a canal location on the right bank of the San Juan.

The parties employed by the Isthmian Canal Commission have developed considerable topography not shown on the author's map; and that map shows some topography not yet seen except by the eye of faith; it would be difficult, however, for one not familiar with the tropical forest conditions, to understand why such small results have been obtained from the large expenditures made in this section. Yet the expenditures have been made carefully, the work has been done with zeal and intelligence, and the apparently small results are due to the peculiarly difficult conditions. In the hill sections one may walk the ridges at a rate of 2 or 3 miles per hour; but in locating canal lines one seeks level ground, which in this region of heavy rainfall is always swampy; here, a transit line, cut through the dense vegetation, resembles a tunnel, and a mere reconnoissance is a formidable undertaking. The trees are much taller in the low ground than on the hills, so that, when viewed from a tree-top or other elevated point, a country of low hills and ravines will look like a level plain. A line may pass within 50 ft. of a hill and its existence remain unsuspected until cross-tunnels are cut for cross-sectioning. In such a country hardly anything is known of the topography except within very short distances of the line run. With a pretty full knowledge of these conditions the

Mr. Noble. speaker must question whether the information concerning the topography along the proposed route is as well known as our sanguine author believes; and has no doubt that those long captivating tangents would suffer if the line were surveyed. It is not likely that the alignment would be materially better than that now obtained on the left bank of the San Juan where the minimum radius is about 5 000 ft., excepting a single curve in the broad harbor channel at Greytown.

It has been held by many that if the Caribbean terminus were located south of the mouth of the Colorado it would remain clear of sand, the San Juan being considered the only channel supplying it, and the drift of sand being supposed to be entirely northward. The investigations of the Nicaragua Canal Commission showed that the sea shore is of sand, as far south, at least, as the mouth of the Reventazon, which drains the southern slopes of the Costa Rican volcanoes; and all the streams of this coast may be sand bearers. To the north of the mouth of the San Juan the sandy beach extends for a long distance, but the streams are not believed to be sand bearers.

The direction of the littoral current appears to be variable. The author states that he observed a westward current "between Harbor Head and the canal mouth" which corresponds to a current up the coast to the northward. The Chief Engineer of the Nicaragua Canal Commission states:*

"The littoral current off this coast is for the most part southward. On the hydrographic charts it is so marked with a velocity of from one to two knots per hour. During the year 1898 it ran southward about eleven months. When the trade winds were mildest the southerly current diminished and finally stopped and then flowed gently northward for about one month. I was told by the sailors and fishermen that this change in the direction of the current was expected by them each year."

It would seem that the author's observations were taken during the comparatively small portion of the year when the current was northerly. The Chief Engineer concludes† that the sand is "not carried by the littoral current, * * * but is urged along the shore by wave action."

The northeast trades blow almost constantly on this coast, which, except in the bight of Greytown, has a general direction only a little west of north. It is not a little puzzling why the trades should produce a sand movement northward. On two occasions the speaker visited the shore a little south of Harbor Head; once near the head of Agua Dulce Lagoon, 6 or 8 miles to the southward, and once near the mouth of the River Indio, about the same distance to the northward, and on both these occasions the sand movement at the beach was to the southward, although small in amount. The speaker does not attach much importance to these few casual observations. The form of the

* "Report of the Nicaragua Canal Commission," p. 61.
† *Ibid*, p. 62.

lagoons near the Colorado mouth, as well as the form of the present outlet, strongly indicate a northerly sand drift in that vicinity. He is inclined to believe, however, that the present movement is not great anywhere, except on the westerly stretch of shore from the point at Harbor Head to the re-entrant angle at the head of the bight. In this stretch the waves raised by the northeast trade fall obliquely on the coast and produce a great sand movement to the westward. This does not extend in large quantity beyond the re-entrant angle of the coast line, the sand being caught and held in the bight. Although the indications are strong that the streams are now bringing down less sand than formerly, the sand movement to the head of the bight may be nearly or quite as great as ever, the sand being now supplied by erosion from the point of Harbor Head, the action now going on being a straightening of the shore line. Mr. Noble.

For various reasons the canal entrance near Greytown has been located in the Greytown bight. One of these reasons, which it is understood controlled the Maritime Canal Company, was the political necessity of placing it in territory undoubtedly Nicaraguan, the exact boundary not having been defined at that time; another reason was to avoid crossing the lower San Juan, one of the delta outlets of the main river, which, even in its reduced condition, is still a large stream and is supposed to carry some sand; and another is the more sheltered entrance to the harbor.

Any harbor jetty located along this westerly stretch of coast will intercept the sand drift, and a harbor will have to be maintained by dredging. The amount may be anywhere from 500 000 to 1 000 000 cu. yds. per year. The entrance to the Suez Canal at Port Said is maintained in the same way under like conditions. The speaker concurs with the majority of those who have looked into the subject, that this disadvantage, considerable as it is, is less than would be encountered at the crossing of the Serapiqui by a canal on the south side of the San Juan.

There appears to be little sand movement north of the Greytown bight. This has led different engineers to propose a harbor near the mouth of the Indio, where the conditions for economical maintenance are probably as favorable as anywhere on the coast.

The speaker will not discuss at length the proposed plan of dam construction. Its location below the mouth of the San Carlos is necessary, for the author's route, to avoid choking the canal with sand at the crossing of the San Carlos. The great pool thus formed would extend several miles above the crossing, and the sand would be dropped at the head of the pool. There being no rock foundation within reach, a rock-fill is, perhaps, the only dam construction practicable at any point below the mouth of the San Carlos. The great objection to such a dam, with an overflow as designed by the author,

Mr. Noble. is that it will not fully serve the purposes for which a dam is required.

In its natural state Lake Nicaragua has an extreme oscillation of from 10 to 15 ft. The variation in any single year may not greatly exceed 6 or 8 ft. If the project of the Isthmian Canal Commission should be carried out, the length of the summit-level from the San Juan dam, up the San Juan River, then across Lake Nicaragua and the continental divide beyond it to the first lock, will be about 135 miles, of which 69 miles will require deepening. Obviously, every foot in depth of excavation is a large amount, and it is extremely desirable to hold the level of Lake Nicaragua as high as practicable. At the same time it is not permissible to raise the high stage of the lake above the normal. The attempt has been made, therefore, to design regulating works which will enable the extreme oscillations of the lake to be reduced to about 6 ft., the range being measured from normal extreme high.

In the lake region the year is divided into two seasons, a wet and a dry. One of the important results of the work of the Nicaragua Canal Commission was the discovery of the fact that during some years the lake inflow is less than the evaporation, and the outflow is at the expense of storage. It would be necessary to build the canal works so that at the close of the wet season the outflow from the lake could be stopped entirely. The crest of the dam, therefore, must be at high-water level or higher. An overflow dam with a fixed crest is inadmissible.

On the other hand, to prevent too high a stage during a wet season of excessive precipitation, provision must be made for a very large discharge from the summit-level. For this, a low crest is required. These two requirements, a high crest during one set of conditions and a low crest during another set, result in a movable dam.

The author's dam, therefore, must be built above the highest water level and have no overflow at any time. Waste-ways with movable crests, or possibly under-sluices, must be provided with a capacity of more than 100 000 cu. ft. per second. No suitable locality with rock foundations at moderate depths is known, and the constructions required would be enormously expensive. A few miles above the mouth of the San Carlos a site has been found where a masonry dam can be placed across the river on solid rock, its crest provided with movable weirs which can be supplemented by a waste-way of similar character on a favorable site, to any extent necessary, and all at reasonable cost. The location above the mouth of the San Carlos is believed to be preferable, not only by reason of more favorable conditions for building, but because it is not necessary to provide for wasting the San Carlos floods.

The speaker believes that the line proposed by the author intro-

duces more serious difficulties than it avoids, and that the dam does not meet the requirements of the problem. Mr. Noble.

* The plan of placing regulating weirs in the San Carlos Ridge has been studied for twelve or more years, and by the three United States Commissions, among others. It is to be considered only in connection with the Ochoa Dam which is located where the San Carlos Ridge terminates, at its northerly end, at the San Juan. This place was not considered favorable for a dam by either of these Commissions, and attention was first given to the search for a better one, and with success; the San Carlos Ridge does not connect with the new dam site, and no further physical examination of it was made. At the new dam site, rock is within easy reach by the pneumatic process, the rock in the adjacent hills affords satisfactory abutments, and a large quantity of water could be passed over it without danger to the structure. In the connecting ridge on the San Carlos side an excellent site was found for a waste-way where hard rock at a moderate depth was developed by borings. The two waterways, counting the dam as one, both equipped with movable dams or sluices, would give a safe control of the summit-level of the canal.

There are several small gaps or saddles in the San Carlos Ridge where the ground is below, or but little above, the proposed summit-level. The engineer of the Maritime Canal Company proposed to build several small weirs and sluices in the ridge, and, at two sites, made a few borings which do not appear to have reached rock, although sunk to considerable depths. The quantity of water to be discharged was greatly under-estimated. The material, a hard clay, might have served for foundations of small structures, but waste-ways for the discharge of, say, 200 000 cu. ft. of water per second, would be enormous structures, and should be founded on hard, sound rock. With rock surface as far down as it appears to be in the San Carlos Ridge, the cost of such structures would be very great.

The clay hills in Nicaragua appear to have been formed entirely by rock decay at the places where they now exist. Many borings have been made on the left bank of the river on the located canal line of the Isthmian Canal Commission. In the vicinity of Ochoa the rock is lower and its upper portion more decayed than further up the river.

The question as to the discharge of the water of the San Francisco implies the canal location through the so-called East Divide. Of course, the waters could be thus discharged, but they could be wasted quite as well, over a waste-way in their own valley, as to be conducted through several canal sections, thus setting up currents therein. The waste-way would be a small structure. The discharge from the San Francisco is smaller than formerly supposed.

* Added to the original discussion after reading Mr. North's question on page 58.

Mr. Hains. P. C. HAINS, M. Am. Soc. C. E.—This project for an alternative route for a Nicaragua Canal comes rather late, inasmuch as the question of route seems to have been settled definitely in favor of Panama. It is understood that the author was employed in Nicaragua by the Maritime Canal Company for a period of about two years, and has given the subject of a Nicaragua Canal a good deal of study. His opinions, therefore, are entitled to consideration. Time will not permit of an extended treatment of this paper, and, under the circumstances, it seems unnecessary, but it is proposed to offer a few comments on certain salient points.

The Isthmian Canal Commission, in its report of 1899–1901, submits a project for a canal in Nicaragua substantially on the route suggested by the Nicaragua Canal Commission in 1898. Starting from Brito, on the Pacific coast, the line follows close to that proposed by Colonel Childs in 1850 to Lake Nicaragua. It then crosses Lake Nicaragua and follows the San Juan River, which it is proposed to canalize, to the neighborhood of the junction of the San Carlos with the San Juan; thence it follows the valley of the San Juan on the north side of the stream. The alternative line proposed by Mr. Le Baron refers only to that part of the route lying between the neighborhood of the junction of the San Carlos with the San Juan and the Caribbean Sea, and passes to the sea on the south side of that stream.

The author states that:

"The importance of good harbors for the termini of the Nicaragua Canal is so great that we could well afford to sacrifice several less favorable features to secure them."

This is true, but there are some features which cannot be sacrificed for any reason. A perfectly practicable plan for a canal cannot be sacrificed for one of uncertain practicability; a plan that is free from all experimental constructions should not be sacrificed for one that is not.

At the present time there is no harbor at either end of a Nicaragua Canal, and this is true whether the route be that of the Isthmian Canal Commission, or the one proposed by the author. Harbors will have to be constructed at each end of the line. Why, then, should any features of a feasible route be sacrificed to obtain what does not exist?

That it is practicable to construct a harbor at the Colorado mouth of the San Juan will not be questioned, but that one exists at the present time cannot be truthfully asserted. Indeed, the author seems to admit this fact, for he states that he "considers it" (the mouth of the Colorado) "well adapted for improvement by jetties"; and, also, that there "seems to be little reason for doubt that this channel can be deepened to 24 ft. by jetties alone." As a matter of fact, very little is known about the actual conditions at the Colorado mouth of the

San Juan River. A survey was made in 1865 by Mr. P. C. F. West, of the United States Coast Survey; and another was made by Commander Tilly, of the United States Navy, in 1898. Neither is really entitled to the name of survey. Only a few soundings were taken on the bar by either West or Tilly, and no tidal measurements were made or other data necessary for formulating a project of improvement obtained. The locality was visited by the Nicaragua Canal Commission in 1898, and again by the Isthmian Canal Commission in 1900. At the time of the latter visit the remains of a wreck were plainly visible off the mouth of the entrance, and the sea, though the weather was normal, was breaking across the entire length of the bar. The "condition of nearly stable equilibrium," which, the author claims, exists there, was not apparent at either time. Still, it will be admitted that the channel might be deepened by the construction of jetties, or by jetties combined with dredging. Mr. Hains.

The author seems to think that the construction of a harbor at or near Greytown is impracticable. In this he differs from nearly every engineer who has studied this question. Many will differ as to the cost of construction. Some may differ as to the causes of the destruction of the old harbor. Some may differ as to the best site available in the immediate vicinity; but none is known to admit that the construction of a harbor is impracticable. The sand movement at Greytown is very similar to that at the Mediterranean end of the Suez Canal, and certainly no one will question the fact that a harbor at the entrance of that canal has been obtained and successfully maintained.

"The futility of building a harbor in the re-entrant angle" (near Greytown), the author states, "is exemplified still further by the experience of the Maritime Canal Company"; and that "the jetty built by them has been overwhelmed by the sands, and the channel they had cut through the littoral cordon enclosing the harbor lagoon filled up shortly after the work stopped."

It is quite true that most of the partially constructed jetty was overwhelmed by the sand, and the channel filled up shortly after the work stopped; but it is remarkable that the engineers composing the Isthmian Canal Commission, as well as others, should draw from the experience of the Maritime Canal Company, in its attempt to form a harbor at Greytown, diametrically opposite conclusions from those formed by the author. This is more particularly strange in view of the fact that the author was employed by that company at about the time the jetty was constructed. The Isthmian Canal Commission states in its report as follows:*

"The feasibility, moreover, of constructing a harbor at Grey Town has been practically demonstrated by the work done by the Maritime Canal Company. About 1 000 linear feet of jetty was constructed by that company at a place a short distance west of the location proposed by this Commission, and where the conditions of sand movement are

* Report of the Isthmian Canal Commission, 1899-1901, p. 141.

Mr. Hains. identical. This was quickly followed by the scouring out of a channel on the lee side to a depth of about 7 ft. This channel was made through the sand spit which converted Grey Town Harbor into a lagoon. The channel was increased in depth to 12 or 14 ft. by dredging. No difficulty would have been experienced in deepening this channel still more, and in maintaining the increased depth by the further extension of the jetty seaward aided by dredging and the possible construction of another jetty on the west side."

It is to be borne in mind that less than 1 000 ft. of jetty were constructed, and the outer end of it, at the time work was stopped, was nowhere near the 30-ft. contour, beyond which it was expected to go to secure the required depth, but the moving sands were arrested by it and accumulated on the windward side, as was expected. The outflow from the lagoon, without other help, opened a channel for itself, 7 ft. deep, which was increased to about 14 ft. by dredging. That a short piece of unfinished jetty should have produced such results so quickly is believed to establish beyond all doubt, if doubt exist, the practicability of thus opening a harbor. The canal engineers regarded it as a practical demonstration of the correctness of the theories on which the plans were based. That a further extension of the jetty (which the plans contemplated) would have been followed by a channel of still greater depth is not to be doubted; that in its unfinished condition it should have been overwhelmed by the sands after work stopped, was to be expected. That this sand movement in the near vicinity of Greytown is objectionable, no one will deny; but that it cannot be stopped by groynes or jetties built out from the shore, no engineer familiar with such work would be willing to assert. It is a far easier problem to solve than many others that are encountered on any Isthmian Canal route. It is chiefly one of expense, and not a very serious one, at that.

The author is in error when he states that "strange to say, only one location for the harbor has been proposed." If he had read the report of the Isthmian Canal Commission* he would have found that an alternative location for a harbor near the mouth of the Indio, about 6 miles northwest of Greytown, is discussed. Not only was the question of a harbor at that point discussed, but an alternative route for the canal from Lock No. 1 to the harbor site was surveyed. The Commission states as follows:

"As already stated, the movement of the sand along the coast, which at Grey Town seems to be at the maximum, decreases as the mouth of the Indio is approached. This stream doubtless brings down some sand and silt during floods. The amount is unknown, but is probably small. Immediately north of its mouth a forest growth, fringing the ocean front, indicates that the shore line is not now being subjected to much change. In view of the small sand movement in the neighborhood of the mouth of the Indio and the apparent stability

*Report of the Isthmian Canal Commission, 1899-1901, pp. 162 and 163.

of the shore line there, it was thought advisable to locate an alternative route from Lock No. 1 to a harbor site at that place." Mr. Hains.

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"This alternative route is of about the same length as the adopted one to Grey Town, but has a little less curvature. The fore shore of the coast is flatter than in the vicinity of Grey Town, requiring longer jetties to secure a harbor. The jetties should converge seaward to give a large area outside the shore line in which the force of the waves may expend themselves, as at Ymuiden. The first cost of this alternative route, both for excavation and harbor jetties, would be greater than that of the adopted one. There is reason to believe, however, that the cost of maintaining the harbor would be less, and possibly the saving in this respect would be sufficient to warrant the greater expenditure for construction."

* * * * * * * *

"The data concerning the Indio route are not so well ascertained as those relating to the adopted route terminating at Grey Town, but its advantage in respect to maintenance of the harbor can hardly be doubted. The Commission believes, however, that it is practicable to maintain a harbor at Grey Town which will be fully as serviceable in every way, and regards its advantages as a working harbor as of such importance that its estimates are based on that location."

The Isthmian Canal Commission does not claim originality in the suggestion of this alternative harbor. Its possible advantages have occurred to others, before. It shows either that the author has not read the report of the Isthmian Canal Commission, or read it to little effect. He says that "The last Isthmian Canal Commission dismissed the idea of a canal on the south side of the San Juan in a few words," and quotes what purports to be a statement of the Chief Engineer to sustain him. There was only one Isthmian Canal Commission. He has the Nicaragua Canal Commission mixed up with the Isthmian Canal Commission, and in reality is referring to the former. The statement of the Chief Engineer of the Nicaragua Canal Commission is as follows:

"An examination of the map shows that a canal location from the Caribbean Sea to Lake Nicaragua, south of the San Juan River, would cross all of these streams." (Referring to the Frio, Poco Sol, San Carlos and Serapiqui.) "This would make its construction practically an impossibility."

The Nicaragua Canal Commission is not responsible for the statement of its Chief Engineer, but it is submitted that this Chief Engineer's statement is absolutely correct. He says that a canal location from the Caribbean Sea to Lake Nicaragua, south of the San Juan River, would cross all these streams, and so it would, as will be seen by an examination of the map, Plate III. In the plans submitted by the Nicaragua Canal Commission it was proposed to canalize the river from the lake to near the mouth of the San Carlos; but that was not the plan to which the Chief Engineer referred.

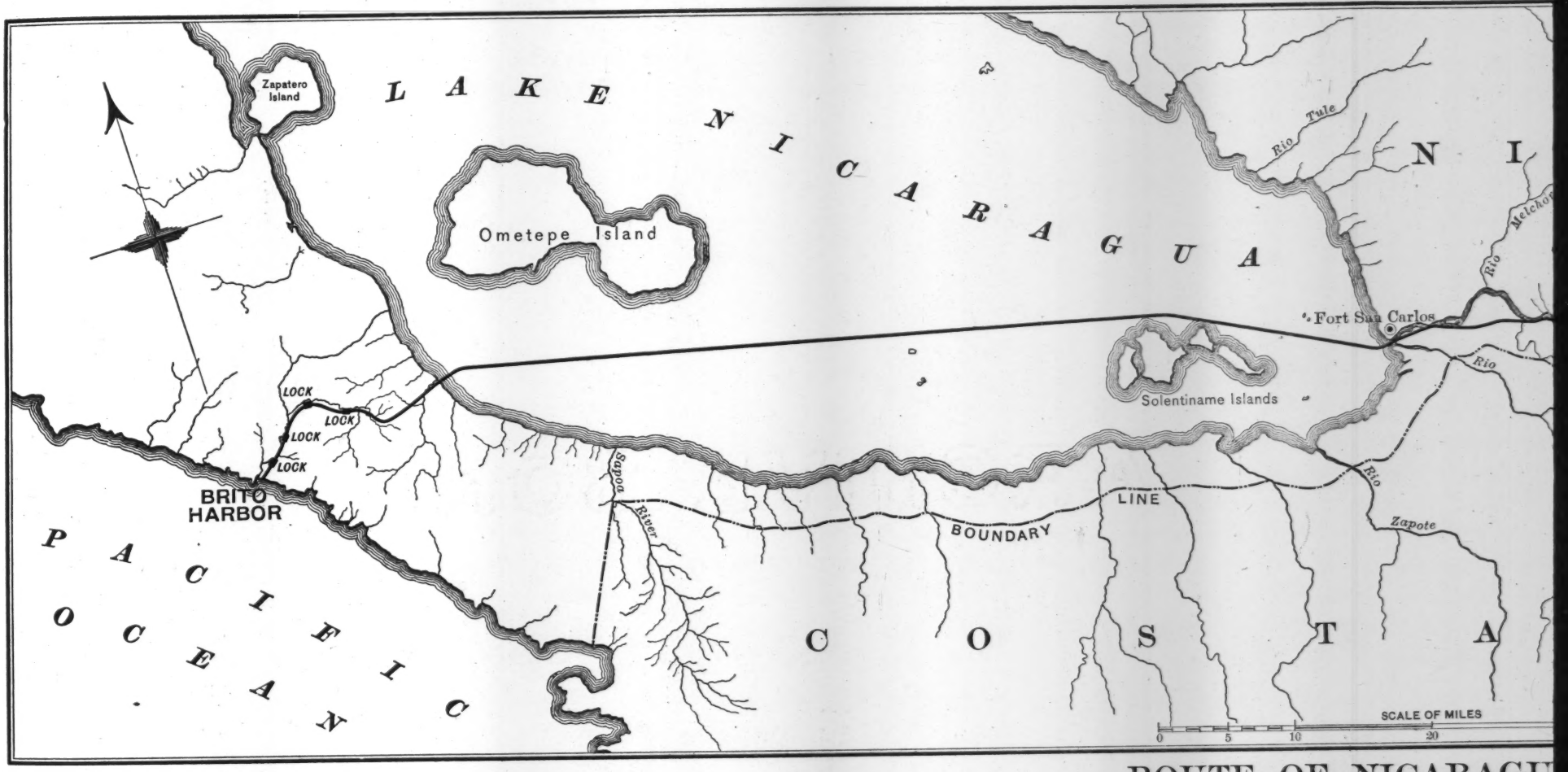
Assume, for the sake of argument, that there may exist a good harbor at the mouth of the Colorado, which is by no means admitted;

Mr. Hains. what are the "less favorable features" of a canal that it is proposed to sacrifice in order to secure it?

First.—The San Carlos must be taken into the canal or canalized river. The canalized river then becomes practically an extension of the lake level to the dam, exactly as suggested by Mr. Menocal. The San Carlos is a torrential stream of no mean dimensions. It takes its rise in the mountains of Costa Rica, and drains a large but unknown area of country. It brings down immense quantities of volcanic sand which have been deposited in the San Juan River from its junction with the San Carlos to the sea. It is an accepted theory that the delta of the San Juan has been largely built of the sand brought down by this river. The sand that now obstructs the bar at the mouth of the Colorado is believed to have come from the mountains of Costa Rica by way of this river and the Serapiqui. In appearance, the sand in the San Carlos bed and that in the delta are identical. When this river is in flood the discharge is estimated by Mr. A. P. Davis, the hydrographer of the two commissions that reported on a Nicaragua Canal Route, as reaching the large amount of 100 000 cu. ft. per second. The San Juan, above its junction with the San Carlos, Mr. Davis' estimates may also reach 100 000 cu. ft. per second when the lake is high and the tributaries of the stream above the mouth of the San Carlos are discharging their flood waters into it. The possible discharge of the two rivers combined make a total of 200 000 cu. ft. per second. An actual measured discharge, made near Ochoa in 1900, was more than 130 000 cu. ft. per second.

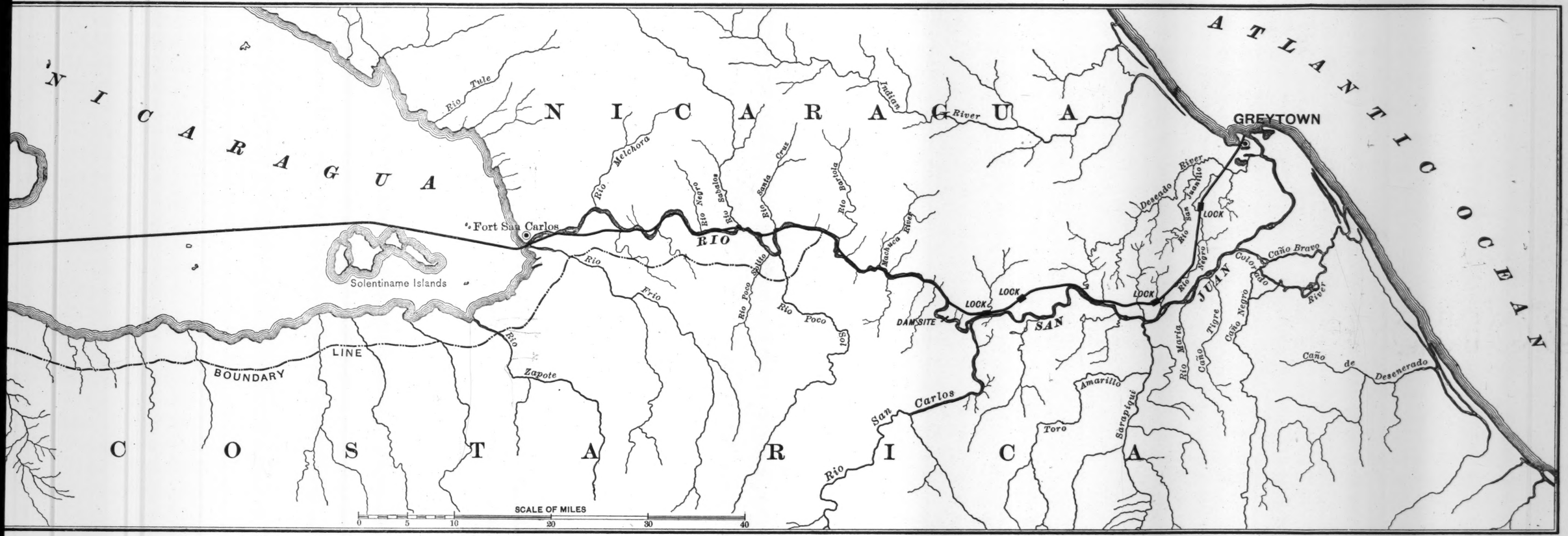
The difficulty of handling this enormous quantity of water is so great that any prudent engineer would prefer to have it eliminated from consideration. It is practicable to eliminate it by constructing the canal on the north side of the river, and as no apparent advantages are gained by taking the south side, all engineers, from Colonel Childs in 1850 to those on the last canal commission, preferred the north side. The first sacrifice, therefore, made to secure this mythical harbor at the Colorado, is the taking of this torrential stream into the canalized river rather than avoiding it altogether.

Second.—The Serapiqui must be taken into the canal. This the author proposes to do in a short section between locks which he proposes to locate on opposite sides of the river. The bed of the Serapiqui is to be used as a part of the canal, but that does not affect the question materially. The full discharge of the Serapiqui must be taken into the canal and let out again. This river is very much like the San Carlos, except that it is not so large. It takes its rise in the mountains of Costa Rica, and brings down large quantities of volcanic sand. Mr. Davis, the hydrographer already referred to, estimates that the discharge of this stream may reach 66 000 cu. ft. per second. To take



ROUTE OF NICARAGU

Recommended by Isthmian Canal Co



ROUTE OF NICARAGUA CANAL

Recommended by Isthmian Canal Commission.

this quantity of water into a long and wide section of canal would be a hazardous undertaking. To take it into a short section would be still more difficult. Actual measurements show that the discharge of this stream exceeds 26 000 cu. ft. per second. Mr. Hains.

The author states that the crossing of the Serapiqui is not more difficult than that of the San Francisco, which is on the north side of the San Juan, "except in degree." A 12-in. projectile striking the armor of a battleship with a velocity of 100 ft. a second will do comparatively little or no damage; but, let it strike with a velocity of 2 000 ft. a second and it may destroy the ship. Yet there is no difference between the two cases except in degree of velocity. The statement that the Serapiqui is only about twice the size of the San Francisco is an error, and a bad one. The Nicaragua Canal Commission made a series of gaugings of these two streams in 1898–1899. These gaugings are published in the report of the Nicaragua Canal Commission. The measurements of the San Francisco, made at the lower station, near its mouth, extended over a period of nine months; those of the Serapiqui, 5 miles above its junction with the San Juan, extended over a period of 11 months. The minimum recorded low-water discharge of the San Francisco was 66 cu. ft. per second. The minimum recorded discharge of the Serapiqui was 2 240 cu. ft. per second. The maximum high-water discharge of the San Francisco was 550 cu. ft. per second, and that of the Serapiqui was 26 731 cu. ft. per second. These were actual measurements made by careful men. They show that in the low stages the Serapiqui discharges about thirty-four times as much water as the San Francisco, and in the high stages nearly fifty times as much. Comment is unnecessary.

Third.—The Caño Negro must also be crossed. Our knowledge of this stream amounts to almost nothing. The maps show its existence. Apparently, it drains a large area of Costa Rican territory, and may be a stream of very large size; but the known physical data in regard to it amount practically to nothing. What difficulties may be encountered in crossing this stream are absolutely unknown.

Fourth.—The Conchuda dam site must be sacrificed for the one at Ochoa. That is, a perfectly practicable dam which involves no untried engineering problems in its construction, is to be given up for a dam the like of which has never before been proposed to the engineering profession, much less built. Whatever opinions may be held with reference to this dam, it is not asserted that it cannot be built. That question will be passed over without other claim than that the building of any dam at Ochoa is a work of great difficulty, while the building of a dam at Conchuda is not; that the dam proposed is experimental; and that the interests involved are so immensely great that, under the circumstances, no engineer would be justified in adopting it. A masonry dam at Conchuda is safe and

Mr. Hains. practicable. It is true that the cost of the project is apparently increased by the acceptance of these safe conditions, but cost is one of the features that can be sacrificed to that of safety in a work of such importance as an Isthmian Canal. What engineer would not prefer to incur an expense of millions of dollars in order to make such an important structure safe? There is to be considered not only the question of money, but that of life also. The destruction of the dam would mean, not only great financial loss, but a fearful loss of life besides.

What are the peculiarities of the dam that the author proposes that are to render it safer than the ordinary rock-fill dam? It is proposed to inclose the loose rock composing the dam within a net made of 1-in. steel cables, the meshes of the net being 3 ft. square and crossed by meshes of still smaller cable. This net is to be laid on the bottom of the river and the dam built upon it. As the work progresses, the up-stream and down-stream ends of the net are to be drawn up, and when the stone fill is completed, the ends of the net are to be fastened together, forming a huge bag of stone.

The author is entitled to full credit for originality in this dam. He says that "an earthquake would only serve to consolidate it and fill up the voids." It is the only dam known that is improved by earthquakes! But has the possibility of the steel cables wearing out, been considered? Has the fact, that in some waters iron and steel undergo chemical changes which destroy their properties, been considered? Has the wearing effect of the sand, washed over the dam by the mighty currents passing over it, been thought of? Steel bolts 1 in. in diameter have been known to be worn through in 24 hours when exposed to the rasping effect of sand in an ordinary centrifugal pump. One of the great difficulties of holding a lightship in position is that the motion of the ship wears out the chain where it comes in contact with the sand at the bottom of the sea.

It is stated that the method of construction will present no difficulties. As the method of construction is not explained, it is not clear that such is the fact. How, for instance, will the lower slopes of the dam be maintained at 1 on 4 during construction if it be overtaken by a great flood? Can anyone say that loose stone, even of large size, will stand on that slope under such circumstances? Will there be no difficulty in drawing up the net on the down-stream side with a mighty torrent passing over it?

The author proposes to construct two spillways in the San Carlos embankment, but says his dam "would be perfectly safe as a weir." It is not claimed that the surplus water may not be discharged over spillways in the San Carlos embankment; but the structures, to be safe with such immense quantities passing over them, should be founded on rock.

Possibly a good rock foundation near the surface can be found, but it is not known that it can. Mr. Hains.

That such a dam could be used safely as a weir, cannot be admitted. To use it for that purpose will necessitate that it be made not only water-tight, because the level of the lake is to be regulated by this weir, but the gates, to regulate the flow of this enormous mass of water over it, must be adjustable and built on top of it. Would any engineer wish to build adjustable, water-tight gates on top of that bag of stone with 100 000 and possibly 200 000 cu. ft. of water passing over it?

The claim that this is not an experimental dam, because a small one has been built in a small stream with sand bags instead of stone, and an ordinary twine net instead of a chain cable net, cannot be accepted. Such a dam, to say the least, is unquestionably experimental. None like it has ever been built under similar conditions. Yet the safety of the entire canal project, involving the expenditure of $150 000 000 to $175 000 000 will depend on this dam. An experimental structure of such a nature has no place in a great project like that of an Isthmian Canal, where so many and such vast interests will be centered.

The members of the Isthmian Canal Commission approached the canal problem with the feeling that a grave responsibility rested on their shoulders. In the minds of the Commission it was a matter of supreme importance that no constructions should be adopted that it was not perfectly feasible to build, and when built, to be safe beyond all peradventure, barring extraordinary convulsions of Nature, for which provision could not be made. It aimed to adopt only such types of structures as had been tested successfully elsewhere under similar conditions, and to reject all structures of a novel type which had not been thus tested. The question of cost was not ignored, but, in the consideration of the problem, it was given a place secondary to that of safety and feasibility. Treating the subject from that standpoint, the Commission recommended a project which was free from all unsafe or questionable structures. Will it not be said that, in this, the Commission was right?

Edward P. North, M. Am. Soc. C. E.—Have those who are studying this Isthmian Canal project considered the practicability of placing regulating weirs, for controlling the height of Lake Nicaragua, in what is known as the San Carlos Ridge? Mr. North.

It has been represented that this ridge, for an approximate distance of 5 miles, has depressions below the desired elevation of Lake Nicaragua. A weir or weirs in this ridge, capable of passing 200 000 cu. ft. of water per second would probably carry the San Carlos sand out of the canal. Nor is there any apparent reason why, with a high-level canal, the waters of the San Francisco could not be passed through the same weir.

Mr. Haupt. L. M. HAUPT, M. Am. Soc. C. E. (by letter).—Although the issue as to the relative importance of the two routes is at present of minor importance, there are certain statements of fact in this paper which seem to be worthy of further discussion.

For example, the author states as follows:

First.—"The greater part of this sand, but not all, comes from the Colorado mouth of the San Juan, and is transported westward by wave action along the beach, on which the waves strike diagonally, under the influence of the prevailing easterly winds."

In the following paragraph it is stated:

"The conditions at the mouth of the Colorado are quite different, and present a nearly stable equilibrium. * * * There has been no appreciable change, up to the present time, at the Colorado mouth, while great changes have taken place at Greytown, * * * The whole geological and physical evidence of this locality points conclusively to the fact that the whole littoral, from the highlands at the mouth of the Colorado to the present canal mouth, is in a condition of constant accretion."

The writer cannot concur with the author as to the interpretation of the physical changes, or their causes, along this portion of that coast, for they seem to be contradictory, and do not appear to conform to the recorded facts. If the greater part of the sand comes from the mouth of the Colorado, it would seem reasonable to find an extended, protruding bar; and, if the conditions are in stable equilibrium, it is difficult to understand how this locality can be in a condition of "constant accretion," or how the northeasterly trades can drive this sand to the bight of the coast and close the former harbor, when the general trend of the coast at the mouth is nearly south, as may be seen from the map, Plate II.

Moreover, the long and narrow lagoons to the northward of the mouth are very suggestive as to the outlet having been, at no very remote date, some 8 miles farther north than it is to-day.

The following extract from the writer's diary would seem to confirm the thought that the littoral drift does not travel from the mouth northward in the face of the winds, but from the salient southward:

"Thurs. Jan. 6th, 1898.—Inspection of beach to Rio Tauro. Breakers discolored for 300 to 400 ft. out, where they begin breaking, probably in 12-ft. depths. Old, large trees of hardwood standing in and on edge of breakers. Have been there about 20 years, according to our guide. (Some white mangroves were 17 ft. in circumference.) Reached the mouth of the Tauro from Harbor Head Lagoon at 3.10 P. M., and found it had shifted ½ mile south of its position on former maps, and, although the sea was breaking normally to the coast, the creepers and drift were inclined to the southward. Frequent outcrops of hard clay protruded into the breakers, showing active erosion, and accounting for the discoloration. The beach formed a rampart about 6 ft. above low water, and its inner slope terminated in a swamp covered with Silico palms."

Mr. Haupt.

The clay *in situ* and the trees of more than a century old standing in the water indicated to the writer that there was erosion rather than "constant accretion," and this view is further confirmed by the comparative study of the charts, for, on January 1st, the diary records that the average recession of the beach at and near the salient east of Harbor Head Lagoon is found to be at the rate of 30 ft. per annum, while, in the bight to the westward, and south of the Rio Indio, there has been an advance of 46 ft. per annum. Between these localities of "cut" and "fill" there is such a neutral axis as the Board of 1895 mentioned in their report, but it is several miles west of the point stated in that report, and only a short distance east of the 1 000-ft. pier built by the Maritime Canal Company. This pier was quite successful in arresting the westward-moving drift and in advancing the foreshore for several miles to the eastward, while that to the westward has receded.

Second.—The author concludes, from the premises, as interpreted, that it is utterly impossible to restore the harbor; and he endorses the location of the entrance at the salient east of Harbor Head, because of the more stable conditions.

An examination of all the available charts from 1832 to date, while on the spot, and a critical analysis and study of the movements of the sandy cordon which finally enclosed Greytown Harbor, have been made by the writer. From these data it was found that the average rate of progression of the point was 291 ft. per annum, and the average quantity of material deposited was 582 000 cu. yds. per annum. "At the same rate, to close the harbor would require 9 000 divided by 291, or 31 years—which, added to 1834, gives 1865, at which date it actually closed."

The capacity of the beach to impound the drift, if a jetty were built out 1 000 ft. east of the present structure and extended 3 300 ft. to the 7-fathom contour, would be 16 600 000 cu. yds., and it would require 29 years to fill it. After this, because of the steeper slope and longer reach, the annual advance of the shore line would not exceed 24 linear feet.

From these studies, the writer concluded that the problem of restoring an excellent harbor was quite practicable and relatively inexpensive. The remarkable series of interior lagoons, lying, as they do, to the west of the river, with their axes nearly parallel to one another and at intervals varying from 3 000 to 3 750 ft. apart, demonstrates the cyclic character of the movement due to the constancy of the prevailing forces, and serves to simplify this problem.

In his report thereon, Professor Henry Mitchell, late of the United States Coast Survey, said:

"The rate of advance will be reduced from year to year, because the base of the triangle will extend farther and farther eastward. * * * The examination * * * has satisfied me that a reconstruction of the harbor is practicable."

Mr. Haupt. His estimate of the average annual drift, based on a shorter period, was 730 000 cu. yds., or more than it is at the present time.

The Isthmian Canal Commission believes the harbor can be created at Greytown for a much smaller sum than at Colon, and has thus reported It has located the proposed entrance to the westward of Harbor Head, as being better than the mouth of the Colorado, and the former has the additional advantage of avoiding the severe freshets and the sediment from the large rivers on the Costa Rica bank of the the San Juan.

The availability of this southerly route, of necessity, must depend upon its accessibility from the sea, and, if it be true that the "greater part of the sand" (if not all) "comes from the Colorado," and two jetties would be required, aided by dredging, to maintain an opening of sufficient depth, it would seem to present a less favorable condition than the point selected by the Commission.

The survey from which the hydrography has been compiled appears to be that made by the Nicaragua Canal Commission, and it shows the direction and intensity of the littoral currents off the mouth of the Colorado to be 0.3 and 0.34 knot per hour, setting to the southward. As this is important in the consideration of the direction of the drift, it should not be omitted from the available data.

Until the question of route is determined finally by the Government, it would seem to be superfluous to consider further the details of this interesting and important subject.

Mr. Paschke. THEODORE PASCHKE, M. Am. Soc. C. E. (by letter).—The author has advanced a new idea in the construction of rock-fill dams. The writer considers the idea of a steel-chain net, in connection with the construction of a rock-fill dam, a step in the right direction, and analogous to the progressive practice of steel and concrete construction in other branches.

Where is the engineer of practical field experience, who, under certain conditions, has found it not to his convenience to use the sand bag; under certain other conditions, the gabion; and, under still different conditions, the timber or log crib for the retention of loose rock? And is the evolution from the latter to the steel-chain net, or bag, such an irrational one?

It seems to the writer that it is perfectly rational, and he concedes most readily any credit due to the author for the novelty thereof.

However, the writer takes serious exceptions to the dependence placed by the author on the steel-chain net for keeping the rock-fill in place permanently in an overflow dam. The writer is very much afraid that all the author's fine calculations would come to naught during an overflow 15 ft. deep, as he has assumed, over such a dam.

But there are other plentiful opportunities, in the large field of our profession, where the engineer, confronted with certain conditions and problems, would hail this idea of steel-chain bags as a God-send.

Mr. Paschke.

For instance, without leaving the field of Isthmian Canal engineering, we need only turn to the problem of temporary dams, as presented by that "old master" of engineering, G. S. Morison, Past-President, Am. Soc. C. E., in his paper on the Bohio Dam, recently discussed by this Society, or, for that matter, to the very rock-fill dams proposed by him. This would do away entirely with the temporary dam, in his case, which latter dam seemed to perturb him not a little.

In other words, the writer contends that, in the construction of rock-fill dams not designed to take an overflow, the use of the steel chain proposed by the author, in net or bag form, as a guard against sudden floods during their construction is entirely feasible and practical, provided the period of construction is not prolonged beyond a few seasons.

The old adage, which is so well exemplified here in our own blessed country and symbolized on our coat of arms, *viz:* "In Union there is Strength," is the underlying principle of the idea advanced by the author; and who will gainsay it?

Mr. Le Baron.

J. Francis Le Baron, M. Am. Soc. C. E. (by letter).—The writer did not expect that the members of the Canal Commission would be swift to approve any change of route of the canal that they had already located after such careful examinations, but he recognizes fully the fact, illustrated so clearly by Mr. Noble, that the Isthmus is a country of surprises, and he felt that possibly a surprise might be in store on the south side of the San Juan, if a survey should be made there. Most of those who have taken part in the discussion have fallen into the error of supposing that the writer advocated this route as a finality, whereas he was careful to state in the paper that he believed the facts warranted a careful survey and examination, and that is as far as he felt warranted in going.

In replying to the discussion, the writer wishes first to mention the map, Plate II. As Mr. Noble surmised, the foundation of this map is the one published in the report of the Nicaragua Canal Commission, which is a reproduction, with additions and corrections, of the map published in the Lull Report of 1872–73. To the Commission's map the writer has added the topography developed by the special surveys and reconnoissances of the Nicaragua Canal Commission and the Nicaragua Canal Board, all of which are published in their respective reports, and, consequently, are official. There is no other topography on the map; therefore, if "only visible to the eye of faith," their correction is due from Mr. Noble and his associates and engineers.

The topography at the mouth of the Colorado is from the survey of Mr. P. C. F. West, Assistant, United States Coast Survey. The writer was very careful to make use of only actual surveys from official sources. In relation to this subject it may be stated that some of the maps of

Mr. Le Baron. Nicaragua and Costa Rica show a cut-off, from the Serapiqui River direct to the sea, called the Sucio River. In case this cut-off exists, the whole volume of the Serapiqui, as well as that of the Tiger and Negro Creeks, could probably be turned through it and discharged ten or a dozen miles southeast of the canal, thus greatly simplifying matters. The writer did not allude to this in the paper, because the correctness of the maps had not been confirmed by actual survey, to his knowledge; but it emphasizes the desirability of a survey and examination on the southern side of the river.

The writer admits that the crossing of the Serapiqui is one of the most formidable engineering features of a line south of the river, but he does not believe it to be beyond the pale of engineering skill at the present day, in view of the experience on the Manchester Canal, and others. He examined the river for some distance above its mouth, and found it to be a deep-flowing stream, between steep banks, with a uniform and moderate velocity, carrying a dark-colored water, which shows that it runs through or drains large swamps, and is entirely unlike the San Carlos, which is very rapid and full of sandbars. In fact, the Serapiqui, in the lower part of its course, flows for a long distance through swamps and alluvial plains, whereas the San Carlos issues almost directly from the mountains. The upper courses of the two rivers are probably much alike. In its ordinary stages the Serapiqui is not a sand bearer in the lower part of its course, where it joins the San Juan. This is shown by there being no sand bank or bar at its mouth. The sand that it carries in its upper reaches is all deposited before reaching the San Juan.

The canal line would cross the Serapiqui within a mile of the mouth, and, by placing a movable needle-dam immediately below the crossing, the depth and velocity could be regulated at the time of passage of every vessel. Vessels would lock down or up on each side, as the case might be, which would be governed by the relative elevation of the water in the canal and river. At all events, the locks would be of low lift, not more than half the total rise of the river, or, say, a lift of 6 or 7 ft., and the canal would be taken into the river, not the river into the canal. When ships were passing, the needles in the dam would be closed, forming a slack-water pool of small extent. When the ship had passed and the needles were opened, the water would quickly return to its former level, and the resulting scour would preserve the depth of the crossing, no weirs or spillways being necessary. The works required would be two low-lift locks and one needle-dam, with their accompanying guard gates, drift fenders and guide wings, the total cost of which might amount to $3 000 000, which would be paid for by 10 to 20 years of dredging at Greytown Harbor, taking the estimate of Mr. Noble; which dredging would be almost entirely eliminated by using the Colorado mouth. In other words, by an ex-

penditure of $3 000 000 for crossing the Serapiqui, and by locating the harbor at the Colorado mouth and using the forces of Nature to scour out the harbor channel, there would be effected a saving of from $100 000 to $200 000, yearly, forever. Mr. Le Baron.

The writer thinks that the charts are at variance with General Hains, as to the Harbor at Colorado. This is a matter of fact, and not opinion. There are open harbors, and there are closed harbors. As shown in the paper, according to the surveys of the United States Coast Survey, a harbor of large extent now exists there for light-draft vessels. The writer has used it—crossing the bar in a vessel of 8 ft. draft. This harbor, as previously stated, consists of Agua Dulce Lagoon, Simon Lagoon and the Colorado River, here about 1 000 ft. wide. At present, for want of more water on the bar, this is a closed harbor to deep-draft vessels; but there is no reasonable doubt that it can be opened by two jetties, as has been done in so many similar places, and, possibly, by a single reversed jetty, on the well-known plans invented by a member of the Commission, and applied successfully elsewhere. Once opened, the current of the river, guided and controlled, will preserve an open channel. Greytown Harbor will require two jetties, and so will the Rio Indio, as admitted by the Canal Commission, and so will any harbor on this coast, Colorado excepted. The latter, possibly, can be built with only one jetty, on account of the strong current and great volume of the river; therefore the position of Professor Haupt is untenable, *viz.*, that the Colorado presents a less favorable condition than Greytown, as the expenditure for jetties would be about the same in both cases.

When making his studies and report on Greytown Harbor, for the Canal Company, the writer was very much surprised to find that the sand movement along the beach, northwest of the Greytown bight, was southeast, or directly into the bight. On the southeast side the movement was in the opposite direction, also into the bight. This was not a temporary drift, but prevailed during the continuance of the easterly winds. The writer's headquarters and residence were on the beach, so that the movement was a matter of daily observation. On account of this sand movement the writer planned the harbor with two converging jetties, placing the easterly jetty 900 ft. east of its present position. It was afterward moved west for some reason, when constructed.

The Isthmian Canal Commission in its report admits* the possibility of two jetties being required at Greytown, and also at Rio Indio, which would each be as long, if not longer, than those required at Colorado bar, and with the additional disadvantage that from 500 000 to 1 000 000 cu. yds. of sand would have to be dredged annually to preserve a channel at Greytown, whereas, at the Colorado, it is probable that, with the channel once established, no dredging, or at least

* Report of the Isthmian Canal Commission, p. 141.

Mr. Le Baron.

only a nominal quantity, would be required, for the reason that at the former place the current is weak and the outflow scanty, whereas at the latter there is a normal discharge of 62 000 cu. ft. per second, and at times nearly double this quantity, and a strong outflowing current to preserve a deep entrance, sufficient, even now, to maintain a channel depth of 30 ft. in the gorge, as is shown by the Coast Survey chart before referred to.

The problem of a canal harbor on the eastern end, then, seems to resolve itself to this: A harbor can be built at Greytown, in the location selected by the Commission, which is a small bight in the coast line, into which is annually being poured from 500 000 to 1 000 000 cu. yds. of sand, as estimated by Messrs. Noble, Haupt and the late Professor Mitchell. This sand movement at this locality has been going on for long geological ages. This is shown unmistakably by the remarkable series of lagoons, some half dozen in number, which have formed back of Greytown at regular intervals, beginning with Silico Lagoon and ending with Greytown Lagoon. The last two—Shephards and Greytown—have been formed in the present or historic age, the latter being completed in 1865, and the former about 200 years before, according to tradition in the locality, which, for confirmation, points to the remains of the old caraval belonging to that redoubtable pirate Shephard, who, in the days of the freebooters, made this lagoon his rendezvous, and from whom it was named. Here he retired after his forays, and, on the last occasion, a storm closed the outlet and the vessel was never able to escape. There it remains to this day, a grim and silent warning of what might happen in the year of grace 2100, in case our dredges should break down or the groynes fail to stop the course of Nature.

It is admitted that a harbor can be built in the place selected at Greytown; but, is it wise to select a point where six harbors have previously been built and filled up? Nothing is impossible in these days of engineering, if plenty of money is furnished. It is admitted that it can probably be kept open for many years by building groynes and by constant dredging, but the groynes must be extended every few years, and the dredging must never stop.

The open book of Nature shows conclusively that here the lagoon-building process is still going on, and sand is being brought in from the north and the south. Year after year the sand that will be dredged from the harbor will accumulate around it; the foreshore will keep on increasing and building out, until at last the advancing mole, as was the case with the last harbor, pushes its irresistible way across the floor of the ocean and closes the harbor, and another lagoon is formed, as has been formed six times before. The delta here has been for ages and is still actively building out into the sea. When Greytown Lagoon was formed, this sand mole, advancing from the south-

east up the coast, crossed the harbor in 48 ft. of water, and in 15 years completely shut up the once fine port. By building a harbor in the same spot we are inviting the same disaster. Mr. Le Baron.

On the other hand, we have the mouth of the Colorado River, a mighty stream, 30 ft. in depth, rolling seaward between banks 1 000 ft. apart, and yearly growing larger on account of the gradual diminution of volume of the Greytown branch, the Lower San Juan. Once inside the bar, here is a harbor capable of accommodating many vessels, as stated in the paper. If this is not a harbor, as General Hains claims, then the Mississippi River from Port Eads to New Orleans is not a harbor. True, the sea breaks on the bar, as General Hains observed; but on what bar does it not break when it has a long reach of deep blue water behind it. The writer, sitting in his office on the beach at Greytown, has seen the spray thrown 20 ft. high, day after day, from the breakers at the site of the Commission's proposed harbor. Breakers in any place certainly do not present very stable equilibrium to a man in a boat; but the fact of their existence being taken to militate against a condition of stable equilibrium of the coastal plain, as General Hains, facetiously, perhaps, infers, is certainly a new postulate in hydrography.

Professor Haupt concludes, from his studies of Greytown Harbor, that "the problem of restoring it is quite practicable and comparatively inexpensive." The datum on which this opinion is based appears to be the fact that a quantity of sand, estimated by himself at 582 000 cu. yds., and by the late Professor Mitchell at 730 000 cu. yds., and which Mr. Noble says may be anywhere from 500 000 to 1 000 000 cu. yds., is deposited annually in the bight where it is proposed to form the harbor; that the advance of the sand mole up the coast was at the rate of 291 ft. per annum, and that from 29 to 31 years, only, would be required to fill or close it. Moreover, he characterizes this movement as "due to the constancy of the prevailing forces"—certainly rather unusual recommendations for a harbor site.

It is true that Professor Mitchell (about 1869) reported that the harbor could be restored. At that time there existed a good, deep basin, fully 30 ft. deep, and more in some places; now, the basin will not average 18 ft. deep, and is not more than half the area it was then. At that time the harbor was worth experimenting with; now, it is not. It is not claimed that it cannot be restored now, but it is submitted that it would be unwise to expend any money on it when there exist other locations free from the deteriorating influences that prevail here. It is sure to fill up at the first opportunity, no matter how carefully it is protected by groynes or pumped out by dredges.

The Isthmian Canal Commission, in its report (page 162), states that "the sand movement along the coast seems to be at the maxi-

Mr. Le Baron. mum at Greytown." It would be interesting to know by what line of reasoning it arrived at a favorable decision to locate a harbor at a point possessing all these disadvantages, and no apparent advantage, except that in its opinion it has "advantages as a working harbor." The writer is forced to agree fully with the Commission in the latter view, considering the amount of sand it estimates must be removed yearly.

The region included between the Colorado and Greytown is a delta, and it is known that deltas are invariably progressive, but, as Professor Haupt very wisely concludes, the movement is cyclic in character in portions of this delta, and this accounts for the erosion at present in the vicinity of the mouth of the Rio Tamo; as Mr. Noble observes, "the action now going on being a straightening of the shore line."

Professor Haupt quotes the writer as saying that "the conditions at the mouth of the Colorado present a nearly stable equilibrium," and that "the whole littoral, from the highlands at the mouth of the Colorado to the present canal mouth, is in a condition of constant accretion," and considers these statements as contradictory. The writer fails to see any contradiction therein, as he states plainly that the accretions commence at the Colorado, where they are zero, and extend to Greytown, where they are known and admitted to be immense.

Now, a word as to littoral currents: These currents, as shown on navigation charts, are apt to be misleading to the engineer, and their value to him, as part of the problem of harbor or bar improvement, depends upon their distance from shore. Where there exists a strong littoral current, a mile or two off shore, running in a certain direction, there is almost sure to be a surf race in the opposite direction, as is the case on the Florida east coast,* the coast of Honduras and at other places, which have come under the writer's personal observation. This is the case here. These contrary currents are in the nature of an eddy, and partially restore the equilibrium of the water. This accounts, also, for the current running in the face of the trade winds, which puzzles Mr. Noble. The writer has often observed this on flat, sandy coasts. It is only in this way that the equilibrium of the sea can be restored. Wherever the sand comes from, it is certain that at Greytown it is continually traveling northwest into the bight of the coast line. This movement was reported by the English engineers, Passamore and Climie, who made a survey of Greytown Harbor for the Nicaraguan Government in 1874, and whose report was published in Spanish by that Government. This survey was made to devise a plan for restoring the Harbor of Greytown, and in it they advocate deepening and jettying the mouth of the lower San Juan River, cutting off the flow from the Harbor of Greytown, which was to be entered from the

* *Transactions*, Am. Soc. C. E., Vol. xliii, p. 95.

river by a tide-lock, they arguing that the increased volume and velocity of the outflowing current would form a "breakwater of water" (*rompolas de agua*), which would arrest this sand drift and thus preserve an open entrance for the harbor to the westward. Just how this would be accomplished was not made clear. Mr. Le Baron.

In regard to the alignment south of the San Juan, Mr. Noble considers that "it is not likely that it would be materially better than that now obtained on the left bank," and states that "the divide is about 50 miles distant." Just what is meant by the "divide" is not quite clear, but it is immaterial. The important matter is the width of the intervale or river bottoms, and this is known to be wider on the south side.

It is known that Colonel Childs supposed that the high hill on the south side of the San Juan and east of the mouth of the Serapiqui was a spur from the Costa Rican Mountains, and he based his project of canalization of the San Juan River on this supposition.

Later reconnoissances proved this to be an isolated hill, with a large and unknown extent of swamp behind it, thus making it impossible to canalize the San Juan by means of a high dam at this point, as proposed by Colonel Childs. Still later, it was hoped, during the several surveys made by the Nicaragua Canal Company, and by the United States, that spurs suitable for this purpose could be found opposite San Francisco Island or Tamborcito and other places, and various examinations were made of the south side for the purpose of discovering such spurs; but all proved futile. These various surveys have demonstrated that the river bottoms on the south side extend many miles south of the river, being dotted with only occasional isolated hills, whereas on the north side, as first stated, the mountain spurs of the Cordilleras come abruptly down to the river in numerous places, and have to be cut through by any line on that side. These facts support the writer's contention that on the south side a very much better alignment can be found than exists on the north side, and the engineer is justified in being more sanguine of finding "captivating tangents" when all the facts demonstrate that the ground for them exists. The experience of large ships in the curves of the Suez Canal shows conclusively the importance of these "captivating tangents," even at the expense of more costly works at the crossing of the Serapiqui. The writer repeats, enough is known of the topography of the south side to justify the belief that the alignment can be bettered nearly 75% on that side; and, while the line, as laid down on the writer's map, may very likely have to be shifted in places, the surveys already made show that no material change need be expected or looked for, as this line is laid down in accordance with known and accurately delineated topography.

The comparison made by General Hains between the anchor chains

Mr. Le Baron.

of a light-ship and the net chains enclosing the rock-filled dam is not appropriate. The anchor chains of a ship are continually in motion, being dragged about on the ocean floor while the ship is tugging and straining at her anchor, whereas the chains enveloping the rock-filled dam will lie almost quiescent, being held firmly in place by the rough rocks composing the dam itself, and, in turn, holding those rocks. Where the ship's chain is continually grinding up the sand between each link and thus always abrading every wearing surface, the net chains will lie quietly in the dam, covered by the rough stones, and only exposed to the abrading action of such sand as is brought against it at a few exposed points, and it will occur to anyone that this chain net can be carried clear across the dam, during the process of construction, every 10, 20 or 30 ft. in height, if desired, and so connected by split links, up and down, and right and left, as to form in reality a number of nets all connected together, so that if it should be worn away at one place it will be held in another a few feet distant, perfectly protected by the enclosed and superincumbent rock. This also answers the next question as to how loose stone will be held on the down-stream slope during a great flood. In other words, there will not be a single net or bag, but a series of nets, one above the other, and all linked together. Neither will it be necessary, as will occur to any practical engineer, to draw the chain up against the stream, but it can be drawn down with the current, and thus spread over the rock.

The rusting of iron or steel under water in the course of ages is, of course, admitted, but in fresh water this is a comparatively slow process. If, for this reason, engineers are to be deterred from using it, three-fourths of the engineering constructions of the present day, such as steel caissons for bridges, piers, etc., must be condemned. A little reflection will show that when these cables are rusted out, a new chain net can very easily be spread over the dam, which, by that time, however, will have become consolidated and stable, except possibly on the crest.

The Conchuda Dam is to be of masonry, and General Hains says this is "perfectly safe and practicable." This cannot be said truthfully of any masonry construction in an earthquake country. As General Hains says, somewhat sarcastically, "a rock-fill dam is the only dam known that is improved by earthquakes," and quotes the writer as saying that "an earthquake would only serve to consolidate it and fill up the voids." The writer repeats that this is his opinion, but he does not claim credit for its originality. This feature of a rock-fill dam at Ochoa was advanced as a favorable one by the consulting engineers who reported on it several years ago. To trust the fate of the canal to a masonry dam, anywhere on the Isthmus, would, in the writer's opinion, be taking chances that no prudent engineer would

care to take if they could possibly be avoided. The comparison of the wearing effect of sand in the bends of a centrifugal pump, having a velocity of 15 to 20 ft. per second in a closed tube, with that of a river current having a velocity of 4 to 8 ft. per second seems rather far fetched. Such terrible abrasion General Hains fears would wear away the crest of his masonry spillways in a short time. The amount of sand abrasion of a wrought-iron rod set in a smooth ledge close to a sand beach, in salt water, at the mouth of a tidal river where the tide-rip, heavily charged with sand, swept over the ledge with a velocity of 2 to 8 ft. per second, was at the rate of 1 in. in twenty years, as observed by the writer. In fresh water it would be less, and it may be safely placed at 1 in. in twenty-five years. Mr. Le Baron.

As a matter of fact, because a rock-fill dam is built at Ochoa, it does not follow that it must be built as a weir. The writer believes, as he stated in the paper, that a dam constructed as proposed would be perfectly safe as a weir, but it is not obligatory to build it as a weir. The dam can be built there, as at Conchudo, above the highest floods, and all the discharge of the river taken over the San Carlos spillways.

The location of a rock-fill dam at Ochoa has been favorably passed upon by two Boards of Consulting Engineers, and, with some modifications, accepted by the United States Canal Board, the first consisting of the Canal Company's engineers, Commander A. G. Menocal, Civil Engineer, United States Navy, Chief Engineer; Lieutenant (now Commander) R. E. Peary, Civil Engineer, United States Navy, Sub-Chief Engineer; the late E. P. Davis, Assistant Engineer, and the writer, at that time Principal Assistant Engineer. At that time more than eight months had been spent in studying the conditions on the ground.

The second Board consisted of well-known engineers, of high standing, not connected with the Canal Company. Of this Board, the late A. M. Wellington, M. Am. Soc. C. E., was Chairman.

The fact that a rock foundation is not known to exist in the San Carlos Ridge, only emphasizes the writer's contention that the south side of the river should be carefully examined and the line surveyed before construction is commenced, in order to compare properly the relative merits of the two plans, which was the only object of the paper; the facts, as the writer believes and so stated, warranting a survey of a route on the south side.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 944.

THE PROTECTION AND IMPROVEMENT OF FORESHORES BY THE UTILIZATION OF TIDAL AND WAVE ACTION.*

By R. G. Allanson-Winn, M. Inst. C. E. Ireland.

With Discussion by Messrs. L. M. Haupt, Francis L. Pruyn, E. Burslem Thomson, F. Collingwood and R. G. Allanson-Winn.

How to safeguard permanently a given line of frontage from the erosive action of the sea at low cost?

This is the problem constantly before the engineer engaged in foreshore protection work. The question of cost depends upon what is to be protected; for an outlay which would be held to be quite reasonable if expended on the protection of a line of railway, the esplanade of a fashionable watering-place, or an important dock or harbor, might be quite prohibitive in the case of mere agricultural land.

Sea-walls, embankments and groynes have all been tried with varying success; and it must be admitted that large sums have often been expended without due regard to the requirements, or an adequate consideration of the complicated conditions obtaining. It is often a matter of extreme difficulty to collect sufficient data to enable one to

* Presented at the meeting of October 15th, 1902.

set to work with any degree of confidence. Among some of the important points upon which information is required may be mentioned:

1. Range of tide.
2. Direction, duration and intensity of prevalent winds.
3. Direction, duration and intensity of most destructive winds.
4. Direction and force of 'long-shore currents, surface and bottom velocities being taken at high water, half-tide, and low water.
5. Percentage of material per cubic foot of water carried in suspension; samples to be taken from the surface and close to the bottom.
6. Quantity of shingle or other traveling detritus, and extent to which it is moved in different conditions of wind, waves, etc.
7. Nature of marl, sandstone, or other material of the foreshore undergoing erosion.
8. Extent to which the sea bottom is undergoing change, especially in the matter of the formation or alteration of submerged banks, causing alteration in the direction of currents.

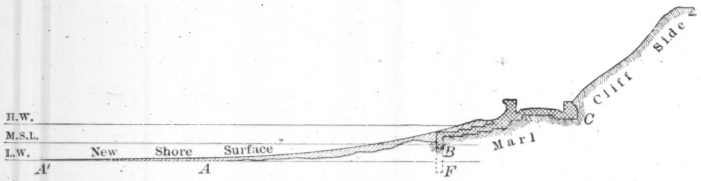
In addition to the foregoing, and most troublesome of all, are the quite indeterminable concurrences of high tides and storms, which, though they cannot be predicted, or calculated with any degree of certainty, must be expected and allowed for. Needless to say, the collection of the necessary data requires both intelligence and experience, for it must be done with a full knowledge of what is required to suit each individual situation—a point of vital importance in one case being of quite secondary consideration in another.

Of all the methods of dealing with sea encroachments, systems of groyning should engage our chief attention, because, by their proper application, we are enabled to direct those great carrying forces of the water, and thus provide for the deposit and retention of millions of tons of sand or shingle which would otherwise be swept away.

With regard to walls, experience shows that they are unsatisfactory, unless they are either protected by natural barriers of shingle

or sand, or built on a scale altogether prohibitive, except for the safeguarding of valuable building property, railways, or docks.

It will thus appear that if we can succeed in accumulating a permanent barrier which will prevent the sea from reaching a wall, except in the form of spray and foam, then, and then only, are we justified in erecting a wall of slight construction.



LIGHT CONCRETE ESPLANADE WALL, STEPPED. OFTEN USED IN CONJUNCTION WITH CASE GROYNES, IN FORESHORE PROTECTION.

FIG. 1.

The section, Fig. 1, shows a wall, *B C*, the foundations of which have been taken well down into the marl, say even as far as mean sea level. Very possibly such a wall may stand for years, but it cannot be relied upon, for, if the shingle, shown in the section as lying above the marl surface, gets washed away, successive laminæ become eroded until, as time goes on, the foundations become exposed, and toe-walls have to be added at great expense, if the wall is to be saved. The writer has now under consideration a sea-wall 20 ft. high, which is being thus undermined, year after year. This wall supports high and easily eroded cliffs, on top of which, and quite close to the edge, runs an important treble line of railway. If the wall goes, the railway must also go, and the anxiety of the engineers, as each line of toe-wall becomes necessary, may be easily imagined.

In all cases where sea-walls alone are resorted to—and more particularly where railway lines or valuable house property are in jeopardy—the writer strongly recommends that the foundations should be at once taken down well below low-water level.

Thus, in the section, instead of stopping short at *B*, the engineer should have taken his foundations down to the point *F*, and thus, at increased initial cost, secured a vast amount of additional future safety.

There is one system of groyning, however*—that discovered by the

* See "The Constructive Power of the Sea." *Proceedings*, Inst. C. E. Ireland, January, 1900.

late Mr. Edward Case—which may be relied upon to collect and retain traveling material in such a way as to protect the toes of walls. Mr. Case took a long step in advance when he promulgated his theory that every shore has its own inclined surface of repose, and that that surface could be brought about by accumulations mainly derived from the traveling material between mean sea level and low-water mark.

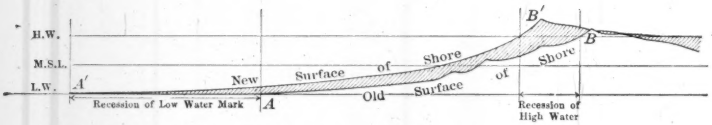
If, he argued, a shore can be made to once acquire this surface—from which there is the minimum chance of alteration through the action of waves and currents—sea-walls, properly so-called, will not be as necessary as formerly for the protection of esplanades, seaside roads, etc. If a good "full" of beach can be secured, a comparatively light retaining wall will be sufficient, for the beach itself can be relied upon as a protection for the foundations, and there will be the satisfaction of having saved heavy expense in costly concrete blocks, etc., which would otherwise have been considered necessary.

Experience and close observation convinced Mr. Case that there was an extensive travel of shore material between mean sea level and low-water mark, and experiments proved that, by the use of long, low groynes, the material-bearing lower currents could be directed shoreward until sufficient deposit had taken place, and the desired surface of repose was acquired. He sought to build up the shore from its lowest point—*i. e.*, low-water mark—and in doing this he was but following the usual custom, for a shore is, after all, but an embankment with a very flat gradient, and, as is well known, every embankment must be started from its foundation or lowest point. Being quite convinced of the soundness of his theory, Mr. Case designed groynes of a form which is simple, inexpensive, and capable of rapid construction. These are low groynes, and are entirely of timber. They were first applied at Dymchurch, which must be regarded as the cradle and home of the Case system. They commence about mean sea level and run down to low-water mark. Among the advantages claimed for those groynes may be named the following:

1. They are economical, as regards time, labor and cost of materials.
2. No plant or skilled labor is required, though experience is needed in the adjustment of the planking.
3. All the timber used is of the same scantling.
4. Manipulation is easy, and the cost of repairs and maintenance is very trifling.

As regards the action of these groynes, it may be observed that the principle of small obstructions and the multiplication of small results gradually brings about the desired change. There is nothing sudden, and no abrupt interference with existing conditions. The deposits are gradually brought about, and at the proper place for the correct building up of the long, smooth bank which is destined to protect the shore at high-water mark. It may also be noted, that the services of that restless, never-tiring workman, the sea, are enlisted, and that the winds and waves help to stir up and carry particles which are caught by the groynes and directed shoreward. In fact, it may be said that the destructive forces of the elements are converted into constructive forces. The small and gradually accumulating silts are encouraged at low-water mark, and further encouraged until the shore is built up to the required shape.

The correct form of any shore composed of beach or any other shiftable material is a gradually sloping surface, the section of such shore between high and low-water marks being approximately an ellipse, the construction of which depends upon the range of tide and the horizontal distance between high and low-water marks. (See Fig. 2.)



TYPICAL SECTION SHOWING ACTION OF CASE GROYNES IN PUSHING SEAWARD BOTH HIGH AND LOW-WATER MARKS, AND APPROXIMATE SURFACE PRODUCED BY LOW GROYNES. THE ACCRETION OF SHORE MATERIAL SHOWN BY SHADED PORTION.
N.B. VERTICAL SCALE EXAGGERATED.

FIG. 2.

Very few natural shores lie at this desirable inclination. The section of a shore between high and low-water marks is seldom a true ellipse, but the nearer the sections of any shores approximate to true ellipses the less damage is done by the sea along that particular portion of the foreshore. In some instances, the curve being nearly perfect and free from any abrupt angles or changes throughout its entire length, the waves roll harmlessly in at the flood tide, and equally harmlessly retreat with the ebb.

Take the case of a railway truck running down an incline of rails and gaining sufficient momentum to run up another incline. If the

rise is quite gradual, and there are no angles or obstacles of any kind, no damage will be done; the truck will run up until stopped by the ever-acting force of gravity, and will then run back again without doing any harm. But if any obstacle is placed on the line, or there is any break in the continuity—any abrupt angle, as it were—something has to go; something is injured or broken.

If any shore, at random, be examined, a well-defined angle will probably be found, somewhere about mean sea level, where the beach leaves off and the sand begins, the beach angle being the steeper from a point above high-water mark to the junction with the sand, and the sand from this point lying at a much flatter inclination right down to low-water mark. No two shores possess exactly the same characteristics. It may be possible to find a couple of places where the nature of the material, range of tide, prevailing wind, etc., seem to be very much the same, but a closer examination will reveal some factor which they have not in common; some particular current, or some sunken bank, perhaps far out at sea.

Roughly speaking, it may be said that there are six types of coast line:

1. The rock-bound coast, where erosion goes on so slowly as to be practically imperceptible—*e. g.*, Cornwall, Aberdeen, North of Ireland.
2. The line where denudation of beach and other shore material is a serious menace to sea-walls, esplanades and cliffs, composed of more or less easily eroded material—*e. g.*, Brighton, Hastings, Folkstone, Ventnor, Shanklin, Sandown, the Holderness Coast of Yorkshire, and, generally, the sites of watering-places all around the coast.
3. Where masses of shingle are being driven inland.
4. Where the shingle has disappeared and there is no "full" of beach to arrest the encroachment.
5. Where shores are so cut about that they consist of bare rocks, pools of water, wet sand and mud, and are therefore most unsuited for recreation grounds for children and others—*e. g.*, Worthing and Herne Bay.
6. Where extensive scours have been caused on the lee sidesof high groynes, as at Hastings, St. Leonard's and Brighton.

As is almost invariably the case with any new contrivance or method, the low groynes were at first looked upon with contempt, partly on account of their slight nature and their cheapness, but more especially because of their novelty. There were also many people who argued that the groynes might answer well enough on a sandy shore like Dymchurch, but that they would be of no use in places where shingle predominated, or where shingle and sand together were to be dealt with. To prove how incorrect these arguments were, we have only to point to Southwold, where there is only shingle, and to Deal, where both shingle and sand are to be found. The writer believes that the principle is correct for any shore whatever, with any range of tide, save, alone, a rock-bound coast.

Dymchurch was in a very bad way when Mr. Case put down his groynes in 1894. The shore then consisted of soft mud alternating with pools of water and wet sand. The Dymchurch sea-wall, extending for more than 3 miles and protecting some 60 000 acres of the Romney and adjacent marshes, was in a precarious condition, and constantly needing extensive repairs. In 1898 matters had improved so much that hard, dry sand had taken the place of the mud and swales, and from 7 to 8 ft. in depth had accumulated near the toe of the wall, which was then practically saved. If placed end to end the Dymchurch groynes would to-day extend for a distance of more than 10 miles. They vary from 300 to 1 000 ft. in length, and have been instrumental in collecting more than 1 500 000 tons of shore material, which lies at a satisfactory slope, and affords an excellent playing ground for children. How many places would be improved by such sands, and how much would such an acquisition add to the value of house property where at present no such sands exist! It is noteworthy that not one of the piles in the Dymchurch shore is set in a solid foundation, and yet there they are to-day, as they were in 1894, having in those few years completely changed the character of the shore and saved the sea-wall. A visit to Dymchurch would go far toward convincing the skeptic, for it would afford a practical illustration of how great results may be produced by the correct application of simple means.

Fig. 1, Plate IV, is a photograph taken at Bexhill, showing the unsatisfactory condition of the shore near low-water mark, and the absence of sand where most required for a children's playing ground.

FIG. 1.—BEXHILL, SHOWING UNSATISFACTORY CONDITION OF SHORE NEAR LOW-WATER MARK.

FIG. 2.—BEXHILL, SHOWING UNEVENLY DEPOSITED SHINGLE AND ERODED CONDITION OF SHORE NEAR LOW-WATER MARK.

Fig. 2, Plate IV, is also a photograph at Bexhill, and shows the unevenly deposited shingle and the eroded condition of the shore near the low-water mark. The Bexhill shore might be enormously improved by the application of the Case system.

At Deal, Southwold, Cromer, Mundesley, and many other places on the East Coast of England; at Borth in Wales, and at Middlekirk and Mariakirk in Belgium, the system has been applied with great success. In 1898 the writer was called in to advise as to the best means of saving the Glenbeigh foreshore, which faces west, and is exposed to the full fury of the broad Atlantic; indeed, standing on this wild Kerry shore, in a westerly or northwesterly gale, one can realize to some extent the carrying power of the ocean. The writer's experience of this foreshore goes back more than 30 years, and, although he cannot remember the time when there was no encroachment, it is only within the past 16 or 17 years that the advance of the sea has become very marked. Nine Case groynes were erected in 1898, and they have been instrumental in collecting a large quantity of sand between mean sea level and high-water mark, and have improved the shore and arrested the progress of the sea. It is only fair to mention that the works at Glenbeigh are very incomplete, the private owners of the estate being unable to afford the cost of a full and efficient scheme.

At Youghal, in County Cork, the sea broke in and flooded 600 acres of land, at the same time jeopardizing the safety of the Great Southern and Western Railway Company's line. An embankment was run across the breach, and the Case system of low groynes applied simultaneously on a scale sufficiently extended to ensure success. The results have been most satisfactory; that portion of the shore which had been cut out, down to the very foundation, having been completely restored in less than a year; as much as 8 000 tons of sand per 100 ft. of frontage having been accumulated by the action of the groynes over a considerable portion of the coast line. The writer formally handed over this work in April, 1901, and it is only fair to say that all interested in the welfare of Youghal are completely satisfied with the rapidity of the work of reclamation.

In proof of the favor with which this work is regarded, it is only necessary to mention that early in the present year, 1902, the Great Southern and Western Railway Company ordered a further extension of the groynes to the west. This additional protective work is now being

carried out under the writer's supervision. It includes a long breast-work wall, five long, low groynes, and an extended sluice-run. The shore in many respects resembles those at Atlantic City and Long Branch, though the New Jersey coast line is more favored—from a groyning point of view—on account of the greater travel of shore material. The writer would be pleased if those interested in the protection of any portions of the United States coast could see for themselves the wonderful results brought about at Youghal in little more than one year, and he has little doubt that they would be convinced by such ocular evidence.

At Bray, near Dublin, the Case groynes are now doing good work, though the results are likely to be less rapidly achieved, on account of the situation and the existence of a sea-wall, which causes a good deal of scour. This work is being carried out for the Dublin, Wicklow and Wexford Railway Company, whose line is now seriously threatened, at intervals, all the way from Killiney to Wicklow on the East Coast of Ireland.

Here there are two obstacles to satisfactory progress in "shore building"—obstacles which do not appear to exist in any of the shores examined by the writer on the occasion of his visit to America—which are of such a serious character that it is out of the question to expect rapid improvement, as at Youghal:

1. The existence of a 20-ft. sea-wall, high-water mark being some 4 ft. up the face;
2. The wholesale and continuous abstraction of shingle, sand, and gravel by one of the foreshore owners.

This shore has been allowed to go too far, and is almost past saving, though there would still be hope if the removal of shore material could be stopped. This material is sold for building purposes at a considerable gain to the owner, but to the great detriment of the railway line which serves the public.

One might almost say, in this case, that the rapacity of Man is leagued with the destructive forces of Nature to defeat the ends of Science.

Fig. 1, Plate V, is a photograph taken at Bray on August 27th, 1901, to the south of the south box groyne—just before its demolition—25 ft. at right angles to the wall opposite the first step in the toe-wall, looking northwest. This photograph shows the deep scour

FIG. 1.—BRAY.—DEEP SCOUR UNDER WALL AND GROYNE.

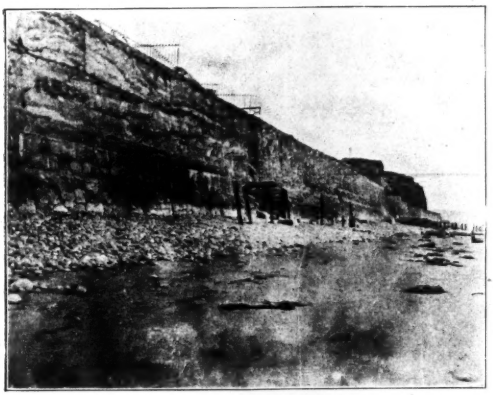


FIG. 2.—BRAY.—ACCUMULATION OF SAND ALONG SHORE.

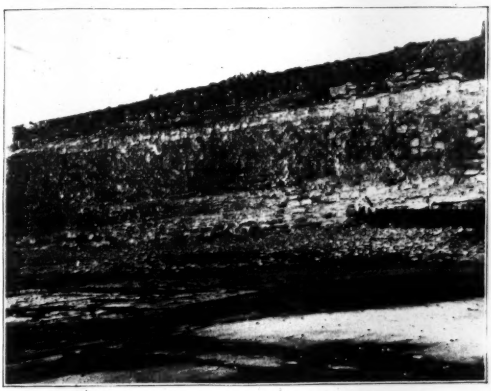


FIG. 3.—BRAY.—SAND AND SHINGLE ON LEE SIDE OF GROYNE.

beneath the piles in the late groyne and the scour under the toe-wall.

Fig. 2, Plate V, is a photograph taken at Bray, and shows the accumulation of sand along a shore where, previous to the erection of the Case groynes, no sand was to be found.

Fig. 3, Plate V, is also a photograph taken at Bray, and shows the accumulation of sand and shingle on the lee side of the high groyne where a deep scour previously existed.

The writer's attention has been frequently directed to the danger of dealing with small, isolated portions of a line of coast, especially where the sections show a very symmetrical accumulation between the highest "full" and low water.

When asked, a few months ago, to report and advise as to the best means of stopping the encroachment of the sea on the Murrough Shore, at Wicklow, what struck him most was the remarkable symmetry of the sections all along that portion of the shore for a distance of more than three-quarters of a mile. The tiers of "fulls" lay so evenly in exact horizontal contour lines that they might have been produced by a gigantic cornice mould. The sections subsequently taken fully confirmed this, for, when superimposed, the plotted sections showed differences of only a few inches.

The next thing which occurred to the writer was the danger of placing any obstacles which might cause the sea to interfere with this symmetry—any obstruction of a solid nature which would cause an uneven scouring action and thus a direct attack by the sea at some definite point, which, in all probability, would be far worse than the gradual but uniform wasting away at present taking place at the rate of about 12 ins. annually all along the entire shore.

Rather than run the risk of almost certain damage by the erection of a few groynes only, the writer refused to have anything to do with the work unless he had the authority of the Wicklow Urban District Council to deal with the shore as a whole, and he then suggested a certain number of Case groynes at intervals of about 100 ft. all along the shore. This could only have had the effect of uniformly increasing the shore material—it could not have caused a scour at any particular point. A short time since, the Urban District Council, entirely disregarding carefully considered advice, invested a considerable sum of money in the purchase of a large barge which they filled

with concrete and sunk in the vicinity of the shingle bank and quite close to high-water mark. Had they wished to aid the sea and destroy their beach they could not have taken a more effectual course. They have indeed done about the worst thing they could have done for that particular shore. The scour around the hulk, in a few weeks, has caused an incursion of high-water mark of 30 ft. on the lee side of the obstruction. The symmetry of the beach is destroyed, and the coming winter will probably see an extensive breach in the immediate neighborhood.

It is a remarkable fact that, while it is usual to secure expert assistance for drainage systems, water-supply systems, road-making, etc., etc., in the case of foreshore protection—a subject of great difficulty and complexity—corporations and private individuals alike are wont to act without advice or in direct opposition to the advice they have received. This sunken barge at Wicklow will have to be removed, and this will probably cost more than was expended in putting it in place. In the somewhat unworthy attempt to get out of paying engineer's fees, etc., this little council of self-constituted experts have run themselves into considerable expense and accelerated the destruction of their beach.

A few more particulars as to actual results may be given here, though the brevity of this paper precludes the possibility of going into many interesting details.

When Mr. Case took the Southwold shore in hand, early in 1898, the waves were constantly breaking down the sheet-piling and the low concrete wall which had been erected for the protection of the rapidly disappearing cliffs. High-water mark was within 41 ft. of the cliff face, and people were deserting their houses, in the full belief that they were no longer safe.

It is instructive to note the gradual and steady improvement which has taken place on this shore since the Case groynes were put down, and Table No. 1 shows concisely the recession of high and low-water marks, and the accumulation of beach, in tons per 100 ft. of coast-line.

Thus it will be seen that this large accumulation of 3 787 tons of material was gathered in, ton by ton, as it were, and that the pushing back of high-water and low-water has been accomplished step by step in a period of 18 months. During the year 1900 the improvement has

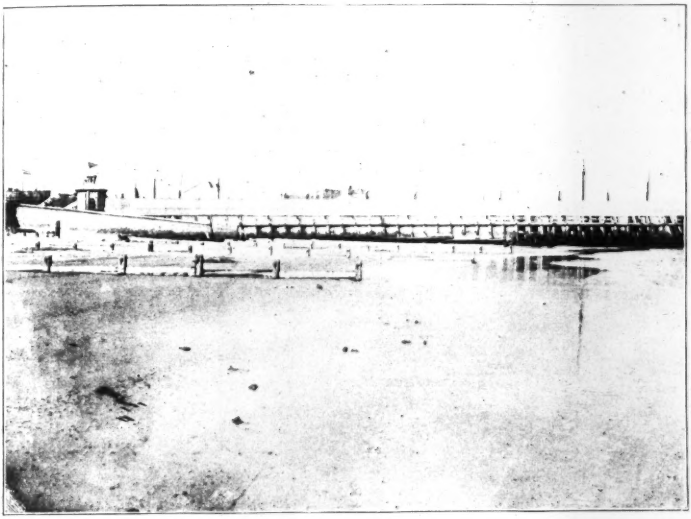


FIG. 1.—LOWESTOFT, SHOWING CASE GROYNES ON SEPT. 25TH, 1898.

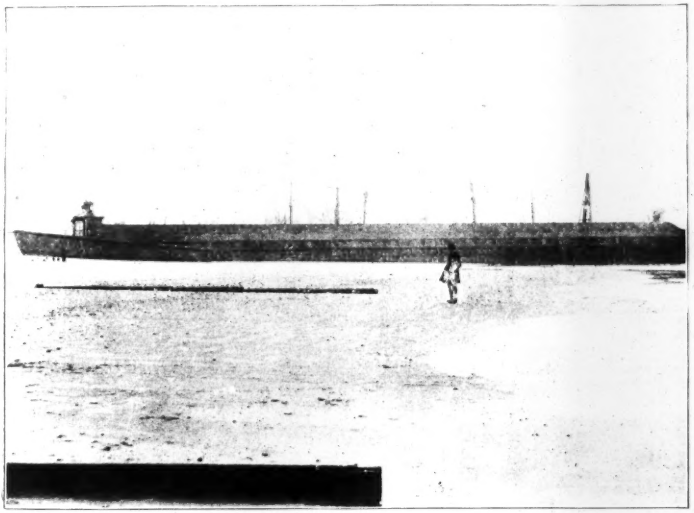


FIG. 2.—LOWESTOFT, SHOWING COVERING OVER CASE GROYNES ON JAN. 18TH, 1899.

been maintained, and the groynes have been raised three times; the land ends of the original groynes having long since disappeared beneath the ever-increasing new shingle bank, the depth of which is between 6 and 7 ft. at its deepest point. The waves of the highest tides no longer reach the toe of the cliffs, and the residents begin to hope that their homes may, after all, escape destruction.

TABLE No. 1.

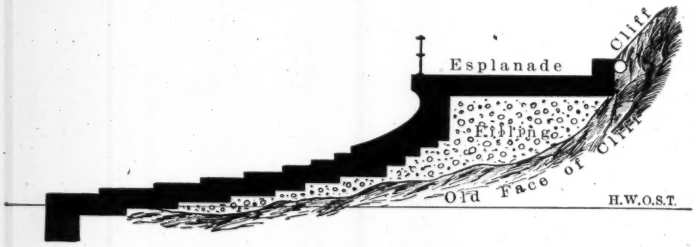
Recession of the Sea.			
Dates.	Distance to high-water mark.	Distance to low-water mark.	Accumulation per 100 ft. on the coast line.
April, 1898, to Sept., 1898	20 ft.	6 ft.	832 tons.
" " " Oct., "	28 "	15 "	1 412 "
" " " Dec., "	40 "	36 "	2 424 "
" " " Jan., 1899	48 "	49 "	3 187 "
" " " Sept., "	68 "	54 "	3 787 "

The action of these groynes is well shown at Lowestoft. Fig. 1, Plate VI, is a photograph taken on September 25th, 1898. Fig. 2, Plate VI, was taken on January 18th, 1899. In four months all three groynes have been almost covered by the deposit of sand and shingle.

At Mundesley, on the Norfolk coast, the system has been applied very successfully in conjunction with a stepped wall especially adapted to meet the requirements of the groynes. As will be seen by reference to the section, Fig. 1, the major axis of the ellipse terminates in the wall just below the promenade. The wall itself is a comparatively slight structure, but quite strong enough to throw back any surface water which, in exceptionally high tides, may be dashed against it in the form of surf. Here, again, attention is particularly directed to the manner in which the whole shore has improved in section. In October, 1898, high-water mark was practically up to the toe of the existing wall; in six months' time it had been driven back nearly 40 ft., and in that same time low-water mark had receded 64 ft. Nearly all the steps of the wall are covered, and there is an accumulation averaging 2 ft. in depth for a distance of nearly 100 ft. Lower down, again, at a distance of 300 ft. from the wall the sand accumulation is more than 3 ft. deep near the wall, and at 361 ft.—which was formerly

the distance of low-water mark from the cliff—there is now a deposit of firm, hard sand, 2½ ft. above the present low-water mark, 64 ft. further on. The accumulation in this instance, between October, 1898, and April, 1899, was calculated at 2 846 tons per 100 ft. of coast line.

Attention is here called to the form of the stepped esplanade wall, Fig. 3, designed by the late Mr. Edward Case and his successors, Messrs. Case and Gray. This wall is light and inexpensive, and is peculiarly well adapted for use in conjunction with the Case system of groyning.



SECTION OF WALL RECOMMENDED FOR USE WITH CASE GROYNES
FIG. 3.

At Sheringham and Beeston, also on the Norfolk Coast, are to be found instructive examples of the treatment of three foreshores, lying side by side, two of them having been treated successfully by the Case system, while the third is at present in a neglected and unsatisfactory condition. The foreshore to the west is the property of a private gentleman (Mr. Upcher); then comes the town foreshore, in the middle; and then the Beeston foreshore, to the east. Mr. Upcher's and the Beeston shores have been and are protected by accumulations brought up by the Case groynes, but the town foreshore is unprotected, and the sea is continually encroaching all along the new sea-wall.

In July, 1900, there was a depth of 6 ft. of water at ordinary spring tides opposite the Crown Hotel. Careful observations and measurements show that in a period of 10 months Mr. Upcher's foreshore had accumulated 1 050 tons per 100 ft. of frontage, and that of Beeston had, in the same time and over the same frontage, gained to the extent of 1 149 tons. All this time the unprotected portion had gone on wasting away at the rate of about 380 tons per 100 ft. of frontage. It

FIG. 1.—CROMER, SHOWING EXTENSIVE SWALE ON OCT. 29TH, 1897.

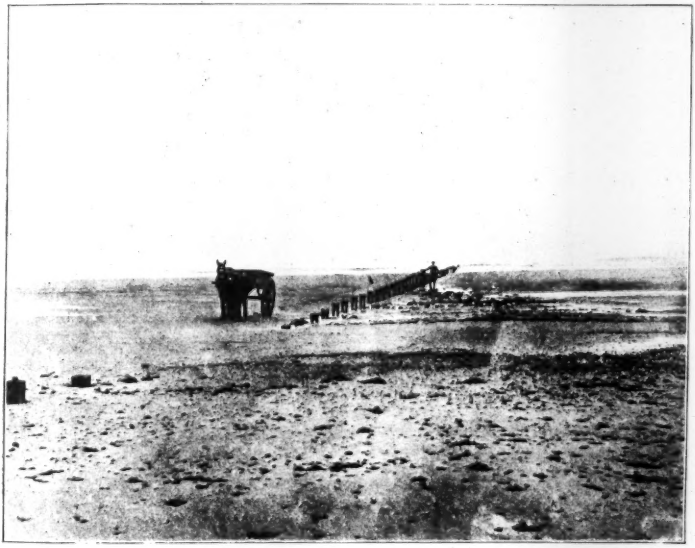


FIG. 2.—CROMER, SHOWING OBLITERATION OF SWALE IN TWO MONTHS.

is also shown that high-water mark has been driven back at Mr. Upcher's and at the Beeston shores, and has as steadily gained on the land opposite the town.

At Cromer, also on the Norfolk Coast (see Figs. 1 and 2, Plate VII), remarkable results have followed the application of the system.

Fig. 1, Plate VII, shows an extensive swale at Cromer on October 29th, 1897; and Fig. 2, Plate VII, is a view of the same place taken two months later, showing the obliteration of the swale as a result of the action of groynes.

The deep scour on the lee side of high timber groynes at Cromer and at Overstrand is shown in Figs. 1 and 2, Plate VIII.

It is a strange and regrettable fact that there are still to be found those who persist in upholding and applying worn-out or obsolete systems, long after the superiority of newly discovered methods has been incontestably demonstrated. Even among engineers in the old country there yet exists a tinge of sentiment in which the unreasoning "follow-my-leader" spirit predominates. Oblivious of the fact that the one great aim of their profession is to utilize and guide the forces of Nature to the greatest advantage for the good of mankind, they, with a truly pathetic reverence for the antiquated, continue to work on lines altogether unsuited to modern requirements.

Becoming stereotyped in their ideas, they are prevented from using freely their intelligence, and marching with the times. Their admiration for some old name or some old school blunts and fossilizes their senses to such an extent that they become incapable of learning. Fortunately, such specimens are rare; and their attempt to stand still in a world of advancement can only lead to their being trampled under the feet of the thousands in search of progress and improvement.

With stick-in-the-mud principles we should have no sympathy, and nothing in common. When the superiority of a repeating rifle over a flint-lock, as a weapon of destruction, has been proved, we no longer go to war armed with the latter weapon; nor do we clamor for the rough-and-ready surgery of the Dark Ages when we know we have better science and appliances at hand. Every scientific manipulation of matter which brings increased efficiency at less cost should meet with attention and support; every step in the right direction should be hailed with delight.

It was pointed out, in the writer's paper before the Institution of

Civil Engineers of Ireland, that, if we turn to a consideration of the actual results produced by high groynes, which engineers have for years past adopted all around these coasts, we will find that, in 99 cases out of 100, scours are caused at the very points which it is necessary to protect. The Hastings and St. Leonards foreshore furnishes an excellent example. It is typical of the high-groyne system. There are deep scours on the lee sides of all the groynes, and the shore, when viewed from the sea, has the appearance of a large saw. Each groyne is a distinct source of weakness to the wall as a whole. The scours to the lee are turned into small deep fiords at high tide, and into these the sea rushes with terrific force whenever there is a storm dead on shore or from the southeast. During such a storm, the wall is attacked at its lowest foundations. On the Hastings shore there is marked scour all along the sea ends of the high groynes, the soft yellow sandstone being exposed and constantly subject to erosion through the sawing action of flint shingle, which is carried laterally along the shore with every tide. In the course of time, this encroachment must reach the line of the esplanade wall many feet below its present foundations, and the expense of underpinning, toe-walls, sheet-piling, etc., will be very heavy. The serious objections to the ordinary high groynes may be summed up as follows: (1) scour close up to the wall; (2) scour at or about mean sea level, and general denudation of the shore between mean sea level and low-water mark; (3) danger to children; (4) impossibility of getting along the beach without the exercise of more than ordinary agility in climbing up or down vertical structures of 8 or 10 ft. in height. It is not going too far to say that one or more of these objections apply to nearly every shore in the British Isles where high groynes have been used.

An examination into the causes of breaches in sea-walls has convinced the writer that the mischief is very frequently traceable to the existence of some high groyne in the vicinity of the breach. Corporations continue to vote large sums of money for the erection of costly high groynes of an obsolete pattern, each of which is in itself a distinct menace; and, regardless of the object lessons with which they are surrounded, really add to the cost of maintaining their walls without bringing about any permanent improvement in their foreshores. The Brighton authorities have expended, and are expending, large sums of money on the unsightly high groynes, and it is not going too far to say that the Brighton shore would be more attractive and more safe

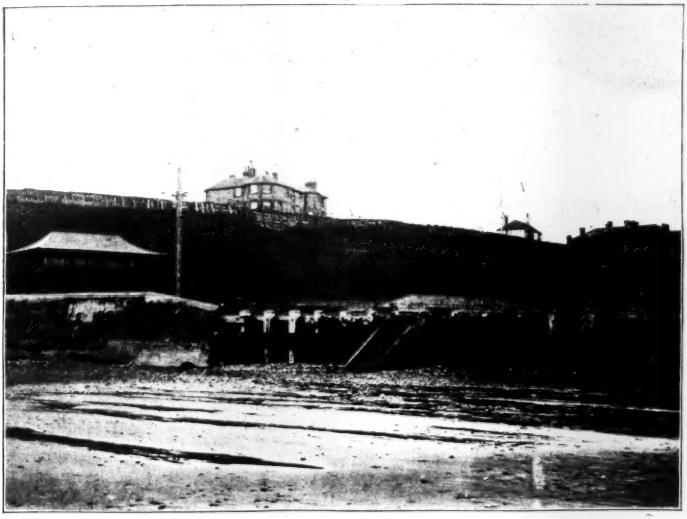


FIG. 1.—CROMER, SHOWING DEEP SCOUR ON LEE SIDE OF HIGH GROYNE.

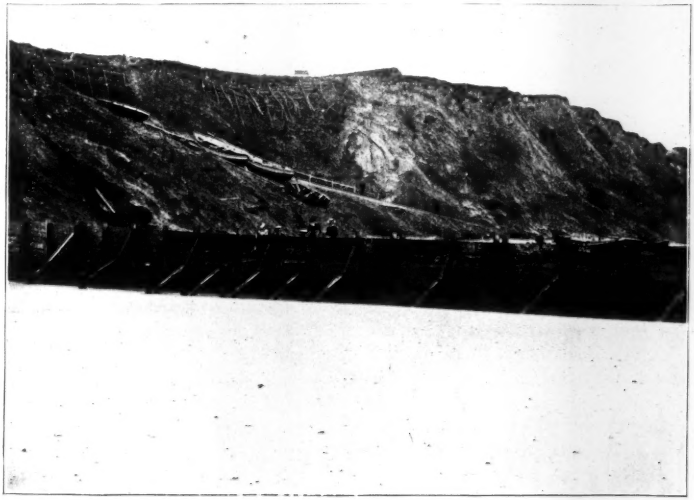


FIG. 2.—OVERSTRAND, SHOWING DEEP SCOUR ON LEE SIDE OF HIGH GROYNE.

had these high groynes never been constructed. The authorities at most seaside places are quite contented to go on spending money, in the happy belief that what was good enough for their predecessors is good enough for them. They have a particular aversion to anything new, and the saving of cost and scientific nature of a discovery seem in themselves to be elements or factors to be regarded with suspicion and disfavor. It was a very long time before Captain Eads could get anything like a hearing when he advanced his scheme for deepening the Mississippi Estuary, and yet the scheme itself was simple and inexpensive, highly scientific, and, as results showed, eminently practical.

The writer has now under his observation several sea-walls where the approach of low-water mark to the foundations has necessitated the addition of toe-walls from time to time, and he can produce abundant evidence to show the damage done by high groynes in such cases, not only near the wall, but at mean sea level, where probably the worst erosion takes place. It would be easy enough to multiply examples of the damage done by high groynes; and the writer will be pleased to furnish actual details with respect to numerous shores, both in England and Ireland, which have been under his close observation for many years past.

The writer regrets that, within the limits of this short paper, it is impossible to discuss even briefly the important questions of traveling material, ocean currents and sub-oceanic deposits, but he ventures to quote a portion of a letter from his pen, which appeared in the *Times* of October 14th, 1899. This letter was written in order to call the serious attention of the authorities to the importance of watching scientifically the coast line all around the British Isles.

"At the present time there is absolutely no official and reliable record of the changes annually taking place round our coasts, and these changes are constantly affecting buildings and other works which have been carried out at a large outlay of public money. Light-houses, coastguard stations, roads, and other necessary structures are maintained chiefly at the national expense, or by county councils and local authorities, and it would, I am sure, be advantageous if annual surveys were taken and returns given which would enable engineers to take the necessary protective steps before any serious damage had occurred. The Admiralty charts are excellent for deep-sea soundings and for the purpose of navigation, but they contain very little information on the question of currents affecting the coast line, and it would require the careful attention of a department to keep a satisfactory record which

could be relied upon when the time for action arrived. As matters stand at present, it is, as a rule, only at the eleventh hour, and after considerable damage has been done, that an engineer is called in, and the mischief is then probably so considerable that only a large expenditure of money can save the situation; whereas, had the note of warning been struck a year or two sooner, the catastrophe might have been averted at comparatively trifling cost. Amongst the duties of the suggested department the following may be enumerated: (1) the systematic and repeated taking of sections (over the same lines) on all shores, as well as contours of high-water, low-water, and mean sea-level lines—this latter is very important, as much damage is done during storms taking place at half-tide; (2) the taking of soundings; (3) calculations based on observations respecting the varying rates and directions of currents at high-water and low-water and mean sea-level; (4) observations as to the velocity and *vis viva* of waves; (5) observations on the travel of beach, sand and other material, especially round headlands, piers, breakwaters, and across bays and the estuaries of rivers. As one of the superintending engineers of the late Mr. Edward Case, I had frequent opportunities of discussing the question with this gentleman, whose system of groyning is now so well known and appreciated at many places in England and Ireland, and we invariably came to the conclusion that the whole question should be dealt with as a national one, and that all shores—save alone rockbound coasts, the alteration in which is so slow as to be practically nil—should be closely watched by the State. The Ordnance Survey maps are, of course, admirable, but they only show the changes in high and low-water marks at long intervals of time. What we require is a succession of observations by means of which any mischief may be readily detected, and deal with it in its initial stage, on the 'stitch-in-time' principle. Did space allow, I could multiply examples of instances where acres of valuable land and house property have been lost, an engineer only being called in at the last moment, when some country road, building, or a railway line was in jeopardy. This kind of thing is hardly fair to the profession, and is analogous to calling in a doctor to see a moribund patient. Cases like this would not occur if the State took the matter up; for the competent men in charge of the department would at once give notice on the approach of danger, which might be threatening, not only the immediate foreshore owners, but the owners of low-lying property far inland, and the proportion of cost to be borne by all interested in the necessary works could then be determined. Procrastination—that worst enemy to economy—would be avoided, and everyone would benefit. How such a department should be constituted, and whether it should be under the control of the Admiralty, the Board of Trade, or the Office of Woods and Forests, are questions quite out of my line, but from observation and experience I believe that a large saving in

the future would result from the adoption of some such scheme as I have suggested."

Soon after the appearance of this letter the writer got into communication with the Board of Trade and the Board of Agriculture, and received the following replies:

"7, WHITEHALL GARDENS,
"LONDON, S. W.,
"October 17, 1899.

(Board of Trade, Fisheries and Harbour Department.)

"R. G. ALLANSON-WINN, Esq.

"SIR:

"With reference to your letter of the 4th inst., relative to a suggested establishment of a department to undertake various duties in connection with the protection of the coast of this country against erosion by the action of the sea, I am directed by the Board of Trade to inform you that it appears to the Board that the proposal, if carried out, would entail very considerable expense, and would probably necessitate the revision of many Acts of Parliament under which the coasts are now protected. In all the circumstances of the case the Board of Trade are disposed to think that the scheme is not feasible at present.

"I am, Sir,
"Your obedient servant,
"T. H. W. PELHAM."

"BOARD OF AGRICULTURE,
"3, ST. JAMES' SQUARE,
"LONDON, S. W.,
"January 6, 1900.

"R. G. ALLANSON-WINN, Esq.

"SIR:

"I am directed by the Board of Agriculture to advert to your letter of the 9th ult., and to say that the Board have read your communication with much interest. The only portion of the work which you propose should be undertaken by the Government which it would be practicable to entrust to the Ordnance Survey is that which relates to the systematic and repeated taking of sections and contours of all shores subjected to change, and the Board do not think that it is at all probable that the Treasury would feel justified in providing at the public cost for the considerable expenditure requisite for the purpose. The Board might, however, suggest that your proposals might be brought under the notice of their lordships and the Admiralty.

"I am, Sir,
"Your obedient servant,
"P. G. CRAIGIE,
"Assistant Secretary."

The serious disturbance in South Africa then commenced, and, with public attention so much absorbed in the war, it was out of the question to worry Government departments with a matter of such secondary importance.

It must be admitted that in Germany the State sets a good example by encouraging such work as that now being carried on by Professor Engels at the *Flussbau Laboratorium* in Dresden. One would think that the wearing away of their native shores should be as important to English, Irish and Scotchmen as the changing of the course of the Elbe, the Rhine or the Spree can be to the Germans. However this may be, in the Dresden Technical School the fullest encouragement is afforded to scientific discoveries and experiments. Models of important rivers are made, and the professor and his assistants are enabled, by the introduction of different colored sands and the regulation of the water supply, to arrive at a very fair idea of what may happen in floods and droughts, where banks are likely to be scoured away and where material is likely to accumulate. Contours of the channels and shore lines of many of the great German rivers have been laid down with accuracy, and Professor Engels has been able to copy in his models all the breakwaters, curves and embankments. The idea is that, by testing certain alterations, such as building dams, reclaiming lands, etc., in the model, engineers may be placed on their guard, and so avoid doing what may lead to useless expenditure. All this shows how keenly the German Government is alive to the desirability of improving—without unduly interfering with the rights of individuals—the general condition of the country.

The gleaming cliffs and yellow sands of Great Britain receive no such attention. It is only when some public road or wall, or some railway line, is attacked that attention is drawn to what the sea is doing, and it is then very often too late to take protective steps, except at great cost. The sea requires constant watching; and the writer contends that if this watching were carried out properly and scientifically, engineers would not find themselves so often taken by surprise, there would be fewer bad cases of erosion, and a considerable acreage might be annually saved.

An inspection of certain shores in the neighborhood of New York City and in New Jersey has convinced the writer that there is a very large travel of material along the coast line, and, from reports re-

ceived, he is inclined to believe that this is the case all the way down the eastern shores of the United States. There is plenty of carrying power in the Atlantic, and, the occurrence of rough weather being favorable to the rapid action of low groynes, there can be little doubt that the Case system would succeed wherever correctly applied for the protection and improvement of those shores.

DISCUSSION.

Mr. Haupt. L. M. HAUPT, M. Am. Soc. C. E. (by letter).—The subject presented for discussion is as old as the sea, and it has forced itself upon the attention of all denizens of alluvial coasts for centuries. Many efforts have been made to resist the attacks of Neptune, but they have been disconnected, impulsive, empirical, and generally useless. In a few notable instances, systematic, persistent, national efforts have resulted in fixing permanently the littoral boundaries, as in Holland and Belgium. Not many years ago it was cheaper in the United States to retreat than to fight the sea. Now, in many instances, it is not so, and the method suggested by Mr. Case, and so admirably presented in this paper by his successor, is based upon the general scientific principle that all materials have a definite angle of repose under certain conditions. This, for a foreshore slope, is claimed to be an ellipse having co-ordinates which must vary as the resultant of all the forces varies. To ascertain the intensity and direction of this resultant is the difficult part of this problem, and it is just here that the skill and experience of the engineer are called into vogue.

The author cites a number of instances where the groynes have been built with great success, and he is correct in designing the work of recovery to operate little by little, making it cumulative. Abrupt angular changes in the direction of littoral currents invite scour and destruction, not deposit and reclamation. The spurs so frequently built at seaside resorts to confine a traveling beach may impound the sands in their bays temporarily, but they invariably show the saw-toothed indentations resulting from the windward side being filled to the crest and the leeward deeply scoured out, so clearly shown in Fig. 1, Plate IX, which is a view of a low groyne at Belmar, on the North Jersey Coast. Similar features are shown in the writer's paper, "Littoral Movements of the New Jersey Coast, with Remarks on Beach Protection and Jetty Reaction,"* wherein the directions of the resultants were stated and the guide to them assigned.

The author mentions eight points which are factors in the problem, and yet there seem to be others, of even greater importance, which must not be overlooked, *viz.*, the general as well as the local contour of the shore, and particularly the prevailing angle of wave approach.

The writer does not understand how samples of the amount of sediment carried by the currents are to be taken at the surface and at the bottom within the breaker line, for each breaker appears to charge itself with a different amount, depending upon the height of its fall, the depth of the receding undertow, the character of material, and other conditions. This is the belt where the erosive forces are most active and where the greatest translation of drift occurs.

Transactions, Am. Soc. C. E., Vol. XXIII, p. 123.

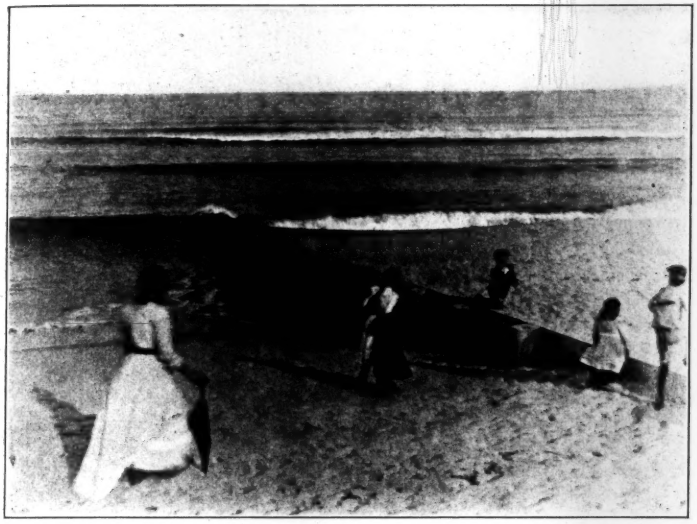


FIG. 1.—A LOW GROYNE AT BELMAR, N. J., SHOWING DRIFT.

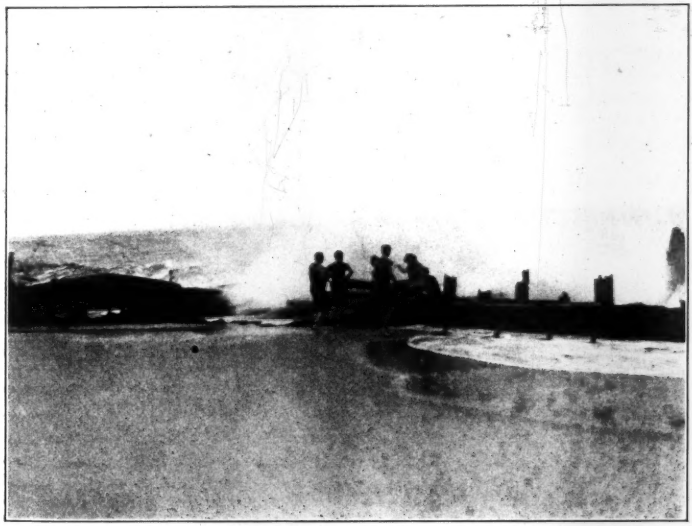


FIG. 2.—WRECK WITHIN BREAKER LINE, AT SEASIDE PARK, N. J.

Mr. Haupt.

The causes of scour at local points are frequently occult, and may be traceable to distant shoals at sea, as the author suggests, but there is one form of foreshore protection to which little or no attention has been given, further than the reference to "Detached or Insular Wave Breakers," in the paper by the writer previously mentioned, where attention is directed to the influence of detached natural features forming strands in their lee in many cases. A recent striking illustration of this action is shown by a wreck which occurred early in 1902, at Seaside Park, N. J., just within the breaker line. In a few months the shore has advanced to the wreck, so that, even at high water, it is possible to walk to it dry shod, as shown in Fig. 2, Plate IX.

In many foreshores there will be found, beyond the breaker trough, a well-defined ridge line, parallel with the coast, and rising above the general floor of the sea. This natural rampart is the proper place for such detached defences or outposts placed within covering distances so as to create a lee. Projecting groynes invariably cause erosion at points below them, unless placed so as to deliver the littoral current nearly tangentially.

The largest piece of systematic reclamation with which the writer is familiar is that at Longport, N. J., where Mr. M. S. McCullough has built an extensive series of sand fences at a very small cost. These have had the effect of impounding a large amount of drift. In many places the beach has been filled from 6 to 8 ft., and the high-water line thrown back several hundred feet. The writer will reserve the details of this interesting work for a subsequent paper.

Mr. Pruyn.

FRANCIS L. PRUYN, Assoc. M. Am. Soc. C. E. (by letter).—The question of shore protection is such an important one to all property owners along the entire coast of the United States that this paper is of great interest. Those who have tried to investigate the subject, and have been met with the total lack of literature on the question of shore protection, cannot help but feel grateful that at last this interesting branch of research has been given intelligent attention and study, and that the results have been published.

The proper treatment of the Jersey shores, which are subject to constant change by the erosion of strong littoral sea currents, has been a subject of some study on the part of the writer for the past few years.

From Sandy Hook to Atlantic City the condition of the beach seems to be more or less unstable. The sand is built up or washed away in an uncertain manner, so that to locate cottages near the shore is often a rather dangerous proceeding. At Long Branch the sea has made almost steady encroachment, and valuable hotels and cottages have frequently been endangered, necessitating the costly procedure of moving the structures further back from the ocean. When visited

Mr. Pruyn. by the writer several years ago, this beach, at several points, had almost disappeared, and the high tide washed up against a low bluff which was protected by strong, heavy bulkheads and occasional pile-groynes. He was told that there had formerly been a wide beach at this point, where now appeared nothing but a hideous bare earth bluff. This also was gradually being eaten away. At other points on the coast, with which the writer is familiar, hotels and cottages have been moved back from the ocean two or three times during the past five years. The protection of the whole Jersey coast seems to be left to the judgment of the local contractor, who follows the rules laid down by his ancestors and never becomes discouraged by the failure of his devices. The systems are all similar, and consist of pile-groynes, spaced from 300 to 500 ft. apart, running from about high tide to low-water mark. In the better class of work they consist of two rows of piles jetted down 15 to 20 ft. below, and rising usually 4 to 5 ft. above, the beach surface. The piles are fastened together securely by bolts and waling strips, and are frequently sheeted on both sides with 3-in. plank, spiked on. The sheeting is to prevent wash through the piles, which would be disastrous to the beach, as the sand on one side of the groyne is frequently from 3 to 4 ft. higher than on the other. The sheeting is usually creosoted, to retard the action of the *Teredo*, and, even then, lasts only three or four years. If the property to be protected is particularly valuable, and the erosion continues in spite of the groynes (which is frequently the case), a pile-bulkhead is driven, a little back from high-water mark and parallel to the beach. This double form of protection with bulkhead and groynes costs from $8 to $10 per foot run of beach, and is variously estimated to be replaced every five or ten years. Notwithstanding this heavy cost, as far as the writer's observations have gone, this system does not protect, after all. The erosion goes on, perhaps more slowly, but none the less steadily; the bulkheads are washed out by the winter storms; the houses are then moved further back; and the process begins all over again. In addition to this, the contour of the beach is unstable, and is constantly undergoing changes. At certain points it will be flat, firm and suitable for bathing; at others, steep, soft and totally unsuitable. The slope of the beach seems to be entirely beyond control. In an instance which came under the writer's observation this summer a costly bathing pavilion had been erected in the previous year, at a point where the beach was particularly favorable for bathing, and this year that portion of the beach was so steep that it was considered unsafe, on account of the undertow, and all bathing was done at a point some 3 000 yds. further up the beach. The same beach which the year before had been comparatively flat, and firm enough to support a bicycle at low tide, was now so soft, on account of its steepness, that in walking one sank in above the ankles.

Mr. Pruyn.

The attractive qualities, and therefore the monetary value, of a flat, firm beach are of considerable importance to owners of seashore property, and its proper contour is only second in importance to the protection of the beach itself. As a matter of fact, a beach with a flat, uniform slope is the only stable beach, for it not only packs harder, but the retreating waves, having a minimum velocity, have lessened powers of destruction.

It certainly appears that the Case system of groyning approaches the problem in a scientific manner, and the writer is convinced that its application to the Jersey shores would procure admirable results. The building-up action begins as the author remarks, at the foundation of the beach, *viz.*, at low-water mark, where the sand suspended in the currents is arrested by low groynes, and is carried up the beach and deposited by the wave action. The groynes, extending only to mean sea level, escape the heavy sea action that takes place above this point, and this is especially true of the heavy winter storms, the destructive action of which is so detrimental to the pile-groynes and bulkheads; for these storms raise the mean sea level several feet above that usual during the summer months. The shorter length of the groynes is an element of economy in their construction, and this feature, combined with the light material of which they are built, makes their cost considerably less than the pile systems described above.

The adjustability of the system is one of its most favorable characteristics. What is aimed at is a slope of beach which will remain stable under the varying summer and winter currents; and, while this angle of repose may be approximated beforehand, it probably cannot be determined accurately for any particular shore, yet by actual observation in each case, as the boards are placed between the upright posts, one can determine when this angle of repose is reached, and the adding of further plank can be discontinued. The short length of time that each plank is exposed to the action of the *Teredo* before being buried by sand would probably not be sufficient to damage it materially, so that the frequent repairs which are necessary with the pile-groyne would not be required.

In closing, the writer desires to thank the author for the presentation of a paper on a subject which has received so little attention from the engineering profession, and hopes that a full discussion will bring to light many facts of interest to all those who have had to deal with the problem that presents itself when man endeavors to interfere with that enormous power, the sea.

Mr. Thomson.

E. Burslem Thomson, Assoc. M. Am. Soc. C. E.—About six months ago the speaker, being in local charge of some work on the Atlantic Coast, was enabled to make some rather crude experiments illustrative of the value of this form of foreshore improvement.

Mr. Thomson. It was necessary to construct a dam to check the encroachment of the sea across a narrow neck of land dividing the mainland from the ocean. The dam was 440 ft. long, and, in front of and normal to it, wings (or groynes) were thrown out, commencing 60 ft. from the face of the dam, at about mean high-water line, and extending seaward 100 ft. to about the line of mean low water. It was intended originally that these wings should be extended right up to the face of the dam, but, following a discussion on the Case groyne system with the principal engineer, it was decided that a space should be left between the dam and the shore end of the wings, thus allowing the waves and currents to pass freely around both ends. In construction, believing the main feature to be the gradual building up of a series of small obstructions, in place of the usual method of opposing a large obstruction to the formidable action of winds, waves and currents, the speaker made no effort to carry out the theoretical details of the Case system as to elliptical form, etc.

Five wings were constructed, 110 ft. apart, extending, as above mentioned, from about mean high to mean low water. They were built of 3 x 8-in. yellow pine planks, dropped on edge and lightly nailed between posts set to receive them. As soon as the sand reached the level of the top of a plank, another was placed above it, and so on. The third tier of planks was recently set in place, and the sand is now within 2 ins. of its top.

In some of the wings, the speaker noticed the tendency to the "saw-tooth" condition mentioned by the author, but observed that this seemed to be dependent on the prevailing direction of the wind. A wind from the opposite direction would correct this condition in a short time, and at present there is no greater difference in elevation than 2 or 3 ins. on either side.

The wings, being built on the shore at the entrance to the harbor, were subjected to tidal currents, the ebb and flood being of approximately equal velocity. Some of the posts supporting the planking were square timbers set about 3½ ins. apart and driven to a depth of 8 to 9 ft. with a pile-driver. The speaker found a more rapid, as well as a more economical, method in constructing them of two 3 x 8-in. planks, set 3½ ins. apart and kept in this position by nailing short cross-bars, in grillage form, at the lower end. This end was sunk 3 ft in the sand, and, when the holes were filled and carefully tamped, the posts were found to be as firm as those driven by the pile-driver. Two men were able to construct and set in place one post in two hours, the average cost for all labor and material being $2 per post.

While this experiment has not taken into consideration many of the conditions set forth in the Case system of groynes, the results, up to the present time, have been entirely satisfactory, and the speaker is of the opinion that this inexpensive form of shore protection will be

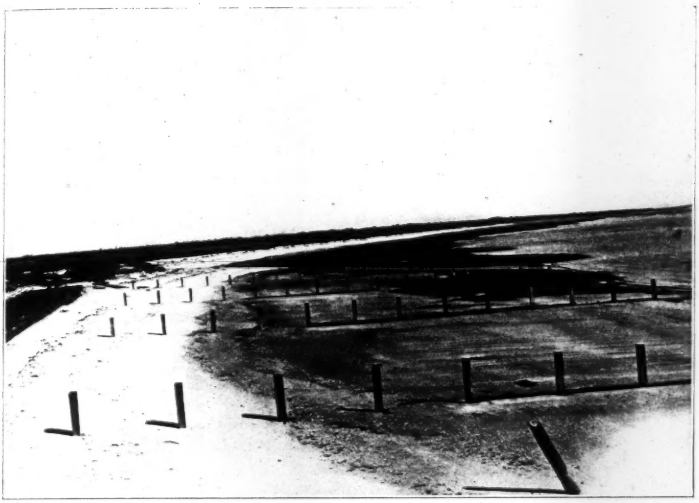


FIG. 1.—BEACH, WITH GROYNES IN POSITION, JUNE 27TH, 1902.

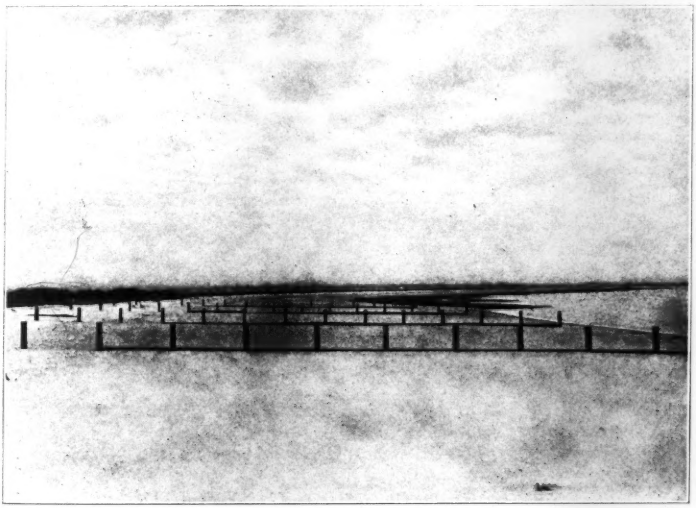


FIG. 2.—BEACH, ON DECEMBER 20TH, 1902.

of great value in the protection and building up of exposed shore lines where the prohibitive cost of masonry and stone construction has prevented necessary improvements. Mr. Thomson.

* Two photographs of the groynes mentioned in the writer's previous discussion are shown in Plate X. Fig. 1 was taken on June 27th, 1902, when the first tier of planks and some few of the second tier had been set in place. These show the irregularities of the beach, as well as the dark patches of marsh mud. Fig. 2 was taken on December 20th, 1902, shortly after the third tier, and in some parts the fourth tier, had been placed. The improvement in the slope and the disappearance of the mud patches, as well as the general rise in elevation, are indicated clearly in these views.

Beyond the region of action of the groynes the mud flats still exist. It is to be noted that the first four posts from the face of the timber dam are not brought into use, the groynes commencing at the fifth post.

F. COLLINGWOOD, M. Am. Soc. C. E. (by letter.)—For some time the writer has been observing the effect of the use of groynes along the coast of New Jersey. In that locality they are always called jetties. As is well known, the ocean shoals very gradually, so that pound-nets are set nearly a mile from shore, and the large waves in a violent storm break about 1 000 ft. out. With the ocean comparatively quiet, the sand is heaped up along the immediate front; but the travel of the waves caused by a northeast or southeast storm cuts down the sand and makes a very long flat slope with a descent of only 4 or 5 ft. per 100 ft. Mr. Collingwood.

Before the regimen of the shore was disturbed by piers, bulkheads or groynes, this cutting and filling nearly balanced, so that the bluffs retreated but slowly. The building of various obstructions, jetties, etc., seems to have caused a deflection of the waves and currents, and has also caused cutting at a rapid rate where the shore is unprotected. Those who visited the steamer *New York*, when stranded at Long Branch, saw a marked example of this.

The same is true at Avon, where, within a few years, the bluff has been cut back at least 25 ft., and the cut now imperils the ocean driveway.

All sorts and styles of protection have been adopted. The earlier attempts, at Long Branch and vicinity, were by bulkheads. These have failed invariably. A wave can be "tired out," but the power of its sweep against a vertical face is tremendous.

It will always be found that eventually a slope will be assumed by the sand, such that a wave will run up, lose its inertia by friction and the lifting of the wave, and come to rest, returning with diminished velocity and less capacity for mischief.

* This part of Mr. Thomson's discussion was contributed subsequently by letter.

Mr. Collingwood. A dyke of fine, loamy sand, built out into the James River for the first Newport News dry dock, was at first cut away rapidly by the waves, which had a sweep of 5 miles; but, after reaching a slope of 1 to 6 and greater, from high water down, the cutting ceased entirely.

The scheme of protection now mostly used on the Jersey Coast is that of groynes; but, as a whole, they are not constructed scientifically. One error, causing the expenditure of a considerable sum at Ocean Grove, and repeated again at Avon last summer, is the neglect to tie or secure properly the land end to the bluff. Although the writer called attention to the matter at Avon, no change was made, and to-day there is a cut landward of some 20 ft. beyond the groyne and around its inner end.

Another fault is making the groyne too high, as a whole. Thi results in a piling up of sand on one side (the side from which the wind may come), and a cutting on the lee side by the water pouring over the groyne. This upholds the claims made in Mr. Allanson-Winn's paper.

A third fault is insufficient length seaward. It is evident that the length should be such that the top of the groynes should be at about low water, and the slope about the same as the flattest slope assumed naturally by the sand when acted upon by the waves.

Of course, at the inner end, this slope must be increased, hence the whole discussion leads to the form adopted in the paper.

When reasonable methods are pursued the result is as may be seen at various points along this coast; the groynes, to a great extent, will be buried in the sand, and the bluff at the inner end fully protected. A length of about 150 to 180 ft. seems to be desirable in this locality, where the tidal rise is nearly 5 ft.

As to distance apart, the practice seems to vary. Manifestly, it must be such that no travel of the waves along the bluff will be possible. This would probably vary somewhat with the direction taken by the prevailing winds. The distance adopted on the Jersey Coast, in many cases, seems to be too great; the same as the length of the groynes would no doubt be safe.

Considerable sums have been wasted by the unscientific treatment heretofore prevailing; and, undoubtedly, the field is one where good engineering would pay.

Mr. Allanson-Winn. R. G. ALLANSON-WINN, M. Inst. C. E. I. (by letter).—The writer agrees with Mr. Haupt that the list of points which are factors in the problem of foreshore protection is not as full as it should be; the general and local contour and prevailing angle of wave approach might well be included, though the latter is governed, to a great extent, by the direction, duration and intensity of prevailing winds.

It would seem hardly possible to collect samples of water, charged with sand held in suspension, from breaking waves at different depths

within or immediately below the waves themselves, and even if it were possible to do so, the conditions surrounding each particular set of observations would be so complicated that any deductions would probably be of little value. The writer is of the opinion that observations such as suggested in the paper might be made with advantage just outside the line of breakers, and, indeed, wherever there is evident discoloration due to suspended eroded matter. Mr. Allanson-Winn.

Excellent examples of detached or insular wave breakers and hidden banks are to be found off the Dublin Coast. Off the Portmarnock line of sand dunes—running almost north and south—are the Islands of Lambay and Ireland's Eye, and it would seem likely that the varying currents brought about by these rocky obstructions would cause frequent alterations in the coast line. Yet the "Velvet Strand," as the eastern shore of the peninsula which terminates in Portmarnock Point is called, is always the same. If any slight temporary erosion takes place, the loss is always made good, and no changes of wind or tide seem capable of interfering with this beautiful stretch of sand.

Further south, the Burford and Kish Banks afford examples of the occult banks to which Mr. Haupt alludes, and there appears to be every reason to believe that, but for the existence of this long line of shoals or string of submerged islands running parallel to the shore, the erosion of the Dublin and Wicklow Coasts would be far more rapid than it is at present.

The writer visited Longport, N. J., and was much interested in Mr. M. S. McCullough's protection works. This was just at the time of the severe gales in November, 1901, when much of the "Board Walk" in Atlantic City was damaged, and about 100 ft. depth of Mr. McCullough's frontage at Longport had been carried away.

Mr. F. L. Pruyn's remarks as to the futility of the ordinary groynes and pile-bulkheads are fully endorsed by the writer. The *Teredo* has proved a very troublesome foe in most of the places where the writer has carried out foreshore works. Ordinary spruce, used for planking up the low groynes, is sometimes so completely honeycombed after three years' exposure to the water that it is easy to push a stiff walking stick through a 2½-in. batten which has been attacked by the worm. Mr. Pruyn has throughly grasped the intention of the Case System, which aims at assisting and not opposing Nature.

The writer has tried many forms of "ringing-engine," but finds that they are all more or less unsatisfactory for driving piles in sand. If the weight is light, the pile will not drive quickly; whereas, if it is sufficiently heavy, it is troublesome to shift. The writer quite agrees with Mr. Thomson that the better plan is to dig them in 3 ft., which is ample for the purpose. In some cases, where the sand is of the nature of quicksand, the digging-in process is troublesome, for the sides of the hole fall in, and the men are standing in wet sand which they

Mr. Allanson-Winn.

vainly endeavor to get rid of by using buckets. In such cases the writer has always used sinking frames just big enough to hold a couple of men. Where a head of water is available, piles could be sunk rapidly and effectively by a pipe and jet.

The east coast of England is in places disappearing with alarming rapidity, and it is very possible that here, as at the places alluded to by Mr. Collingwood, damage may be accentuated very considerably by the erection of jetties and other similar obstructions. As he very truly points out, money has been wasted in unscientific work, but the difficulty is first of all to persuade the "man in the street" that he is not necessarily a foreshore engineer himself, and then to get him to call in someone who really knows something about the business.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 945.

THE SANITARY DISPOSAL OF MUNICIPAL REFUSE.

AN INFORMAL DISCUSSION.*

BY MESSRS. RUDOLPH HERING, JOHN MCGAW WOODBURY, H. DE B. PARSONS, W. F. MORSE, GEORGE A. SOPER, THEODORE HORTON, W. J. BALDWIN, CHARLES B. BALL, M. N. BAKER, ELMER W. FIRTH, MYRON S. FALK, CHARLES H. HASWELL, W. H. BOOTH, H. A. YOUNG AND RUDOLPH HERING.

RUDOLPH HERING, M. Am. Soc. C. E.—The subject herewith presented for discussion embodies the treatment of the miscellaneous solid materials which are not removed by water carriage in underground channels, but require special cartage, and the best disposition of which is not yet generally recognized. The subject, in fact, is still under development, and, it seems to the speaker, has now reached a stage where it requires the assistance of the civil engineer to bring it to a satisfactory state of practice. Mr. Hering.

For convenience of discussion, perhaps also of treatment, the materials included may be divided into four classes:

I.—Ashes;
II.—Street sweepings;
III.—Dry rubbish;
IV.—Kitchen garbage, swill or slop.

* At the meetings of December 17th, 1902, and January 7th, 1903.

Mr. Hering. The problem before the engineer, therefore, is to effect a sanitary collection and disposal of these four classes of refuse at the least cost. For this purpose he must ascertain and carefully consider:

A.—The objectionable qualities of each class of refuse, viewed from a sanitary standpoint; which means the destruction of disease germs, the avoiding of a nuisance and the seeking of comfort and decency in the handling of this matter.

B.—The cost of collection from the place of origin to that of final disposal, and the cost of final disposal, modified by any credit that may be due to a salable value of any part or parts of the refuse.

A.—Sanitary Collection and Disposal.

I.—Ashes.—The objectionable feature in the collection and disposal of ashes is the dust. When placed on the sidewalk, when carted through the streets, or when dumped while the wind is brisk, the arising of dust is a nuisance.

The evident and simple remedy against dust, when collecting ashes, is the use of covered receptacles and covered carts, and, when disposing of them, is a careful and slow dumping, or, on special occasions, perhaps also a prior wetting. The average of city ashes has no manurial value.

The filling in of low ground is the usual way of disposing of this material permanently. Occasionally, it has been utilized as an ingredient for mortar or for road-making.

II.—Street Sweepings.—Street sweepings consist of horse droppings, accumulations of general city dust and refuse not separately removed, and earthy material worked to the surface of pervious pavements or brought by wheels from country roads.

The composition of sweepings, therefore, varies chiefly with the quantity and quality of traffic, the kind of pavement, and the distance from unpaved roads. The sweepings may contain a large or a small proportion of organic matter, some of which may break down rapidly and some slowly. The fineness of this material is its chief objection, as the wind readily takes it up and blows it about, to the injury of man, of beast, of food and of certain kinds of property. Germs of the most prevalent city disease, tuberculosis, may be abundant in the street dust, and the troubles of the continual warfare against this dust, when settling in the rooms of our houses, are known to all.

Sprinkling and sweeping at frequent intervals are the recognized, though often inefficiently executed, remedy against the dust nuisance within the city, and covered carts are also here required for the proper removal of the material.

Its final disposal can be effected in either of several ways. When mixed with or without fuel, and when containing but little inorganic matter, it can be burned, thus destroying effectually the organic matter,

including disease germs, contained therein; or, it can be dumped for the filling of low land, which can be quite satisfactory in many cases. When dumped, the upper surface of the fill alone remains exposed to the wind, and this only temporarily until vegetation protects it. When street sweepings contain a large proportion of organic ingredients, as horse manure, they are utilized as a fertilizing agent, with more or less success, and with the concomitant elimination of their objectionable qualities. Mr. Hering.

III.—Dry Rubbish.—The dry rubbish of a community consists of that aggregation of material which is not classed especially under the other headings. It consists chiefly of wood, paper, straw, leaves, rags, leather, stoneware, glass, metals, and sweepings from buildings. Its most objectionable qualities are dust and lurking disease germs. It is not easily decomposed, and its odor, usually, is but slightly offensive. Its value consists partly in the material that may be picked out, assorted and sold, such as metals, glass, and other discarded articles of manufacture, and partly in the fuel constituents which it retains after such picking.

Its collection should be made in covered carts, to prevent odors, dust, and other nuisances. The frequency of collection is not an important question, due to the stable character of the material.

Its final disposition, after it has been picked over, is usually either as filling of land, by dumping, or as fuel, by cremation.

Filling up low land with this rubbish was an early practice, and still persists in many places. Where land is available, where such material will not cause future trouble, and where it cannot be burned economically, this practice cannot be seriously objectionable. Where the rubbish can be properly burned, such practice would generally be preferred by the medical profession.

IV.—Kitchen Garbage, otherwise called Swill or Slop.—Garbage proper is the refuse chiefly from kitchens, markets and slaughter houses, and consists almost wholly of rejected animal or vegetable matter in solid and liquid form. A large proportion, therefore, readily breaks down, and, on becoming putrescible, disperses offensive odors.

It is the most important part of city refuse, both because it is likely to create the greatest nuisance, and because it has the greatest inherent commercial value. It has been the subject of more discussion, its treatment has been more varied, and a satisfactory solution of the problem of disposal is less generally acknowledged, than in the case of the other classes of refuse.

Regarding the best manner of collecting this material, there is but little question. It is generally conceded that it should be placed in water-tight and covered receptacles, and collected in water-tight and covered carts or wagons. It is also conceded that the collection should be frequent. The frequency, however, varies often with the

Mr. Hering. density of population. Yet this density affects only the quantity of the material, not its liability to putrefy, which is controlled wholly by its composition, the length of time it is exposed, and by the temperature. That the latter fact is beginning to be recognized in some cities is evidenced by ordering more frequent collection in summer than in winter. The necessary frequency should also vary with the manner of disposal. If, for instance, garbage is fed to swine, then, for sanitary results, a daily collection is peremptory throughout the year, except only in very cold weather.

In northern climates, where winters are cold and long, the receptacles, for obvious reasons, are better made of wood than of metal, while in warm climates the reverse is true, which conclusion is already recognized occasionally. Where garbage is likely to freeze while waiting for a collection, a conical-shaped receptacle is the only proper form.

The final disposition of this material is now being effected in the following ways:

1.—Feeding to swine,
2.—Dumping as filling,
3.—Dumping into large volumes of water,
4.—Ploughing into soil,
5.—Extracting the grease,
6.—Cremating the organic matter.

Feeding to Swine.—This was one of the first methods of disposal ever used, and it is still practiced extensively. In New England it is the prevailing method in small and medium-sized communities. If kept free from other refuse, and from such as would injure its food quality, if collected and delivered properly daily, there seems to be no serious objection to this method, either from a hygienic or commercial standpoint. It has an advantage over all other methods in yielding a revenue from its sale, which is sometimes greater than that obtained through any other method of disposal. Its application, however, must be confined to conditions under which the sanitary quality of the food, respecting disease germs and odors, can be safely guarded and maintained, and which excludes it from adoption in large cities, except in the case of hotels and eating-houses, where a private collection can be secured.

Dumping as Filling.—This is practiced in places where feeding is found objectionable. When not mixed with other refuse, dumping is objectionable on account of the subsequent putrefaction, in case of a large accumulation of the garbage. When mixed with other refuse, the merits of dumping depend on the proportions of the ingredients of the mixture, and on the character of the locality where dumped. Under some conditions a nuisance would, and under others would not, result.

Dumping into Large Volumes of Water.—This method can, or can not, be advised according to the special conditions of the case. Like the disposal of sewage by dilution, a safe disposal of garbage can be effected by dispersion, if the quantity of water is sufficient, if the current or winds prevent a drift ashore, and if the sinking material does not accumulate so as to reduce the necessary channel depth for navigation, or produce foulness by deposit in shallow water. Opportunities for a satisfactory disposal in this manner will be rare. Mr. Hering.

Ploughing into Soil.—This has been practiced with varying success. If freed from metals and large entangling objects, and if mixed with barren sandy soils or acid soils, garbage being somewhat alkaline, good results have been obtained for the raising of crops under careful management. This process is at present considered favorably in several cities of Europe, because it can dispose of disease germs and odors satisfactorily, and because the gradual nitrification of the organic matter has produced a fertile soil where sterility had previously prevailed.

Extracting the Grease.—The extraction of grease from garbage is an American industry which has been promoted in a number of our cities. The process in its general form consists briefly in separating the material into two parts, each having a salable value, namely, oil, or fat, and a dry, somewhat stable, fibrous material of vegetable and animal origin, called tankage, and used as a filler or diluter for certain fertilizers. The separation is brought about by simple boiling and subsequent pressing out of the oil and water, which are in turn separated by gravity. Or, it is accomplished by an admixture with naphtha, which dissolves the oil, and later, after it is separated from the tankage and cooled, enables it to be readily extracted. The water separated from the oil is an offensive liquid, and the gases and fumes generated at the works are offensive vapors. Both require a careful and thorough treatment.

The objections to this reduction method of garbage disposal, which is still practiced in Boston, New York, Buffalo, Philadelphia, Washington, St. Louis, Cincinnati, etc., although abandoned in some cities, is due to the offensive odors occasionally, if not continually, arising from the same. The process requires the rejection at the works of tin cans and other foul material which interferes with the economical process of securing the oil. For such rejected material a different treatment and disposal is necessary. While, from an engineering point of view, it is practicable to construct and operate these reduction works so that odors will not prevail, the means for doing so are also expensive. As they are operated invariably as a business undertaking for profit, the conflicting interests naturally involve the constant danger of a possible nuisance. The practical result has been that, for the sake of sanitary security, such works are now placed as

Mr. Hering. far from inhabited territory as practicable, with the disadvantage that the distance for transportation has become correspondingly greater.

The advantages of this method lie chiefly in the commercial value of the oil and in the destruction of disease germs and putrescible matter by heat. There is little value in the tankage, which is used occasionally as a fuel or even wasted on dumps.

After all the operations of a reduction process have been conducted without offense, the financial aspects will decide the permanent merits and value of this method of disposal.

Cremating the Organic Matter.—This is the favorite and exclusive method of garbage disposal in England, where it has been used for fifty years; and it is also the favorite one of the medical profession. In the eyes of the sanitarian the complete destruction by fire of all matter that may become offensive, and at the same time of all disease germs that may lurk in the sweepings of the house and in the rejected food materials, is an ideal process.

In practice, however, the results have not always been ideal. In our country odors from such works have been complained of in many instances, and a number of crematories have been abandoned as nuisances. In England, however, such has not been the case. Furnace extensions are built every year. Complaints are rare. In Hamburg, Germany, where is the largest single garbage crematory in existence, this is giving no offense, although adjoining a built-up section.

An examination into the reasons for the different results achieved by cremation in Europe and America shows that the elements making up the problem are not the same.

1.—The material as it is burned in Europe has not the same composition as that which here has failed to burn properly. European success was achieved with refuse generally consisting of a mixture of garbage with ashes and dry combustible rubbish. The chief failures in America are recorded where garbage alone was cremated, without the admixture of other combustible dry refuse, and even after the addition of furnace coal. An examination into the combustibility of European and American combined refuse does not show a great difference. The few analyses we have show that cremation under proper precautions and suitable conditions should be as practicable here as in England, and recent furnaces built here demonstrate this fact.

2.—The essentials in the construction of the successful English furnaces differ from those of the furnaces peculiar to our country, where they have not been satisfactory. The English furnaces are built with sloping grates of small area, while the American furnaces generally have horizontal grates of large area. It is hardly necessary here to point out that in this element lies a main defect of our plants. A sloping grate admits of an almost automatic, continuous process of gradua drying, then heating, and finally burning; the fresh material

being added at the upper end and the hottest fire being near the lower end. A horizontal grate, on the other hand, to secure proper combustion, depends almost wholly upon stoking. It causes the burning to be irregular, due to the sudden dropping of cold and perhaps wet material upon that which is already almost completely burned. In Europe we also find an extensive use of large dust chambers to prevent the escape of this fine material, of which we so often hear complaint. We find also a more frequent and effective placing of dampers to control the draughts, and thus prevent the escape of unburned, and therefore odorous, solid particles and gases. Finally, more attention is directed there than here to the evolution of the greatest possible heat for the incidental production of steam. Mr. Hering.

3.—The expert garbage fireman, who is considered essential to success in England, is generally supplanted here by a man whose only qualification for the position may be that he can shovel coal or pull out clinkers, but generally has not the remotest knowledge or even conception of the difficulties in burning, on a large scale, both continuously and completely, the most heterogeneous mixture of all forms of solid matter to be gathered from a modern community. The advantage of a trained expert in firing city refuse was well shown by the fact that until Hamburg imported English firemen to train the German firemen in the mere operation of their own plant, satisfactory results could not be obtained.

4.—In Europe, the municipalities, under the guidance of experienced engineer officers, generally undertake the cremation by their own long-trained employees, while here, usually, either the health boards or council committees select not only the design, but indicate the method of operation, appoint inexperienced employees, or enter into a contract for immediate profit rather than for permanent efficiency. The difficulties underlying the problem of city refuse disposal, which is almost wholly one of engineering, have been solved satisfactorily where competent engineers have been employed for the purpose. It is hardly to be expected that, without professional skill and training, desirable results can be reached in this, any more than in any other, branch of engineering.

It will therefore rest finally upon our profession to solve this urgent question in our country, by not only making the necessary preliminary investigations to determine the most economical means of disposal, to indicate the methods, and to design the works that will accomplish this in a sanitary and inoffensive way; but, also, by indicating the details of operation most suitable for the particular kinds of material delivered.

B.—Cost of Collection and Disposal.

In discussing this subject, in full view of what has been said regarding the sanitary demands, we are now able to add that the latter

Mr. Hering. demands can be satisfied by the engineer in any and all of their aspects if the necessary price is paid. He is therefore obliged to estimate, here, as in his other problems, the cost of each method, developed to a point of satisfactory efficiency. The least expensive of the several possible methods will then become the preferable one. As the question of cost embodies the collection, from the point of origin to the point of disposal, the estimate must embody the expense required between these two points; for one process may require a much longer haul than another; then, to be economical, the disposal in the first case must cost proportionately less than in the second.

Theoretically, it would be proper, in a given case, first to estimate the cost of properly collecting and disposing of each class of refuse, separately, in accordance with the several practicable ways indicated. Then it might appear that perhaps some two or three or all four classes of refuse could be treated economically by the same process. In this event a second estimate of cost would be appropriately made for a system of combining the collection and disposal of two or more such classes of refuse, and thereby the expediency of a system of separation or combination, in part or as a whole, would be ascertained. In practice, this procedure sometimes might be very simple.

In making such estimates of cost it is necessary to take account of both debit and credit sides of the financial aspect.

The collection is a debit in every case, its amount depending upon the distance the refuse is hauled. When garbage is fed to swine, the collection should be more frequent than in other cases, and a further debit would be proper on that account.

The final disposal has both debit and credit sides to be investigated. In the case of kitchen garbage and dry rubbish a substantial debit is required in establishing preventive and precautionary measures against the arising of offensive odors, of dust or other nuisances, in whatever process of disposal may be considered. On the other hand, the credits must be determined, as the case may be, and, if found to exist, they may be given to the several classes of refuse as follows:

Ashes.—By filling land, utilization for road-making, or as an ingredient of mortar, or otherwise.

Street Sweepings.—By making land or by utilization as manure, or otherwise.

Dry Rubbish.—By utilizing whatever value exists in the pickings, and in the remainder as fuel for power purposes.

Kitchen Garbage.—By utilizing its value either as food for swine, as grease and fertilizer, as a heat producer for power development, or otherwise.

If the subject under discussion is treated substantially as above outlined, the speaker believes: First, that, through the co-operation of

the engineering profession, it will gradually cease to be a vexed question among our legislators; secondly, that the sanitary demands, in preventing nuisances and dangers to health, will be satisfied; thirdly, that the economical advantages inherent to the several processes will be secured; and fourthly, that the result will be an efficient process operated at the lowest cost. Mr. Hering.

JOHN MCGAW WOODBURY, Esq.*—In a large city, all sorts of wastes are found: Wastes of ashes, garbage, street sweepings and rubbish; the rubbish consisting of paper, broken-down sofas, discarded mattresses, old shoes, bureaus, washstands, broken crockery, dolls, toothbrushes, tin cans, rags, bottles. Every conceivable kind of waste is either found in the streets, or is put out of the houses, for the city to dispose of. What shall be done with it, has been and is still the question. Heretofore, in New York City, most of these wastes have been disposed of by the archaic method of dumping them into the sea. This is but an extension of the first idea of disposal, which was to throw such wastes into the street. Mr. Woodbury.

This idea of final disposition of refuse still exists in less civilized communities, particularly in tropical countries. It is practiced all through the West Indies, the only sewer being an open one running through the center of the street, into which it is the general custom to throw all wastes, including offal. They have but little ashes, and the carrion crow and turkey buzzard are the common scavengers.

In New York City, at present, the speaker happens to be the common scavenger. In Paris, in the time of Louis XI, there was an order appointing the hangman as the common scavenger, and giving him permission to remove dead horses and cattle from the streets. The world has made much progress since that time.

The problem of garbage disposal is a vexing one. By the reduction process, phosphates and grease are obtained. By the incineration of garbage it is claimed that heat can be obtained, and that this will generate power; but all experiments in New York City show that it takes fuel to burn the garbage in a sanitary manner. The question of cost is important. The best or most scientific and sanitary process is not the best, financially.

Fig. 1, Plate XI, is a photograph of a flat scow being unloaded in the ocean, outside of Sandy Hook. It shows clearly the quantity of flotsam, much of which will be distributed along the beaches a little later.

Fig. 2, Plate XI, shows the Barney Dumper being unloaded at sea. It is a divided boat, or catamaran, and splits in the center, thus dropping its load. It is a great improvement over the flat scow.

The Delahanty Dumper, going to sea under its own steam, is shown

* Commissioner of Street Cleaning, New York City.

Mr. Woodbury.

in Fig. 1, Plate XII. It is also a catamaran, having pockets hung between the two hulls. Doors, hung by hinges in the bottom of these pockets, are opened and closed by steam power, thus discharging the refuse. By the use of this vessel the refuse is disposed of at a cost of about 19 cents per cubic yard.

One of the dumping boards of New York City, with two Barney Dumpers and a flat scow, is shown in Fig. 2, Plate XII. This method of loading scows is also very archaic, as the ashes and light refuse are blown about by the wind. At these dumping boards, and on the scows while being loaded, a number of men are always engaged in picking over or sorting the refuse and trimming the scows. Quite a revenue is obtained by allowing the material of value to be picked from the waste, besides the advantage of having the scows properly loaded.

The output of rubbish and ashes from New York City is about 2 000 000 cu. yds. per annum. If the rubbish is separated from the ashes, it means a great deal, financially. At Riker's Island land valued at about $10 000 an acre is now being made by using the ashes as filling, which is certainly more economical than throwing this material into the sea and letting it go to absolute waste. Ashes make the best possible filling, and pack well behind the cribs, which are sunk on the mud bottom.

It is of the utmost importance that dumping at sea be stopped, not simply because it makes the beaches unsanitary and unsightly, but because it is a waste of valuable material. The separation of refuse is now in good condition. The quantity of garbage sent to the Sanitary Utilization Company in 1902 was 30 000 tons more than was ever sent in any previous year. This quantity of garbage has come mainly out of the ashes. The rubbish, also, is now kept separate in parts of the city, thus leaving the ashes almost a merchantable commodity.

For the disposal of rubbish Mr. Parsons has designed the incinerator on the pier at Forty-seventh Street and North River. It is burning about 60 loads of 5 yds. each, or about 30 tons in eight hours, every day. This rubbish consists of excelsior, mattresses, trunks, barrels, boxes, chairs, sofas, paper, rags, etc. These, in burning, produce sufficient heat to make steam in boilers, which will furnish power to run a belt-conveyer, now being constructed, which will be used for sorting the material. The surplus power will be used for lighting, for the elevator, for a traveling runway to the dumping board for loaded trucks, and possibly there will be some power which can be sold.

The City of New York now receives $110 000 a year for the privilege of sorting, and when greater facilities are given the sorters, as by the conveyer mentioned, a much larger sum will be realized.

Aside from the sanitary handling of the refuse, 63 acres of land have been made at Riker's Island, which is equivalent to $630 000; the

FIG. 1.—UNLOADING REFUSE FROM FLAT SCOW, OFF SANDY HOOK.

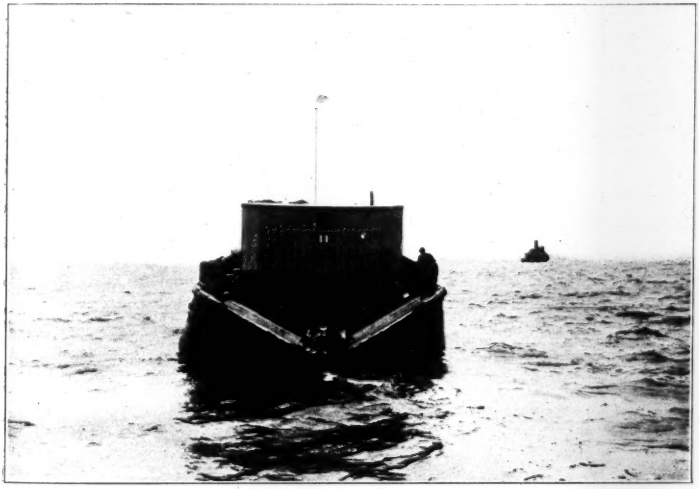


FIG. 2.—THE BARNEY DUMPER, BEING UNLOADED AT SEA.

privilege of picking over the refuse has been sold for $110 000 for the year; and the utilization of power from burning the non-marketable refuse will bring the total income up to about $900 000 a year. In this way the city's wastes become a source of revenue which will help materially in cleaning the streets. Mr. Woodbury.

H. DE B. PARSONS, M. Am. Soc. C. E.—The primary collection of the refuse of a municipality is made by carts, which convey the waste material to points for final disposition. This primary collection presents no special difficulties. It is a matter of carefully working out the details to suit best the existing conditions. Mr. Parsons.

The problem that is serious and difficult to solve is that of the final disposition of this refuse—a problem which is closely allied to the health of the community. The direct benefits derived by a suitable system for sanitary disposal are augmented indirectly by an increase in the health of the community.

No matter how the question is approached, the practical considerations of first cost and expense of operation and maintenance will be found paramount. On this account, as well as the short tenure of office of our city authorities, systems have come into use which are neither the most sanitary nor most economical for final disposition. Contracts have been let for such short periods that contractors have refrained from erecting suitable plants, and systems have been evolved which only earn for the cities a portion of the direct returns that might be obtained.

The refuse of a municipality consists of garbage, ashes, rubbish and street sweepings. In an average American city the divisions are proportioned approximately, as follows:

	By weight.	By volume.
Garbage	13 per cent.	18 per cent.
Ashes	80 "	57 "
Rubbish	7 "	25 "

The statistics gathered from one city are not applicable to another; and results predicated on information obtained from other places will not always be satisfactory. In order to make a final solution of the problem, it is necessary to study the conditions obtaining in the particular place under consideration. Garbage is combustible. It is extremely difficult, however, to burn pure garbage, and it has been found necessary to mix fuel with it in order to obtain complete combustion. The amount of fuel required varies from 8 to 20% of coal by weight, according to the character of the place and the constituent elements of the garbage. Ordinary kitchen garbage consists of approximately, by weight:

Animal and vegetable matter	20 per cent.
Grease	3 "
Water	70 "
Rubbish, cans, rags, etc	7 "

Mr. Parsons. Ash collections are divisible into two kinds, steam ash and household ash. The steam ash, produced by manufacturing companies, comes to a city dump practically pure. It is clean and contains little unburned coal. The household ash, on the contrary, contains a large quantity of unburned coal. It has been estimated that, in a city like New York, the quantity of unburned coal in the ash carted to the dumps from private houses and apartment houses amounts to about 20%, and, in the speaker's experience, there is little question but that the proportion is correct. This coal, mixed with the ash, can be and is utilized as fuel to assist in the combustion of garbage. The ash collections make a good filling material, and can be disposed of for that purpose.

Rubbish collections are very combustible, as are also the street sweepings.

Final disposition of the refuse may be made, first, by dumping on waste lands, or at sea; secondly, by sending the garbage to reduction works, cremating the rubbish, and utilizing the ash collections for filling; and, thirdly, by cremating the garbage and rubbish, and utilizing the ash collections for filling.

The first method is neither sanitary nor satisfactory.

The second method is sanitary, but not wholly satisfactory. The reduction works can only handle garbage, and the system is considered uncertain in case of an epidemic, as the employees might refuse to work the plant. Such works can only afford to operate on a bonus paid by the city. The process consists of extracting the moisture by pressure, as being cheaper than evaporation, and of cooking the material by steam in large tanks or digesters. The products are grease and a residue sold as fertilizer. The plants are expensive to construct.

The third method is sanitary, and, in the speaker's judgment, the best; because it has been accomplished without creating a nuisance, because it is the most sanitary, and because it can be made to produce the greatest revenue. To be successful, the combustion must take place at a high temperature, say between 1 500 and 2 000° Fahr. The household ash, the rubbish and the street sweepings will supply the fuel.

Cremation has been tried, in a number of places in America, with poor results, although very successfully practiced in Europe. The failure in American cities has been largely due to faulty design of the furnaces, lack of high temperature (a most essential feature), and want of means for properly caring for the garbage when first brought to the destructor. When garbage is allowed to collect in mass, it is most highly objectionable, and such collections have caused, in some instances, the failure of what otherwise might have been a successful plant. The heat generated can be used for various purposes and be made income-earning.

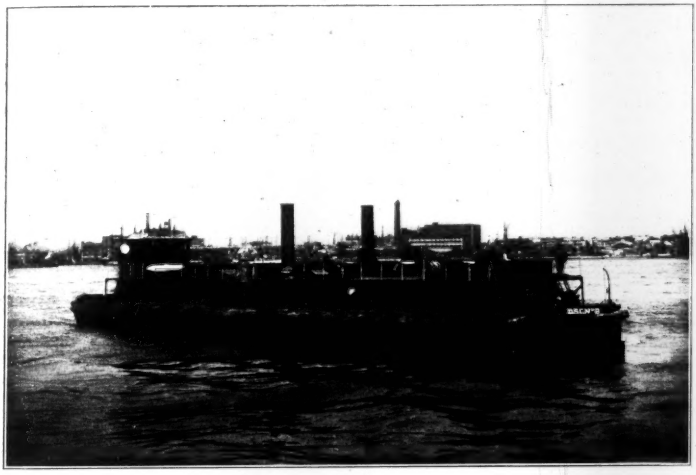


FIG. 1.—THE DELAHANTY DUMPER.

FIG. 2.—LOADING SCOWS WITH REFUSE.

CONDITIONS IN THE CITY OF NEW YORK. Mr. Parsons.

Area of Greater New York	320	sq. miles.
" " Borough of Manhattan	39	" "
Paved Streets, Greater New York	1 000	" "
" " London	1 818	" "
" " Paris	604	" "
" " Berlin	500	" "

The amount of refuse collected yearly in the Boroughs of Manhattan, Bronx and Brooklyn is about 2 800 000 tons. The collections, in pounds per capita per week day, are about as follows:

Garbage	0.4 lbs.
Ashes	2.5 "
Rubbish	0.3 "
Street sweepings	0.7 "
Total per capita per week day	3.9 "

Comparing this record with other cities, of which the records are believed to be fairly accurate, the following comparison is made:

New York	3.9 lbs. per capita per day.
London	1.6 " " "
Berlin	0.9 " " "

Results varying so widely show the difficulty in predicting what can be done with a municipal refuse, unless one knows in advance the character of the waste.

The rubbish collections in New York City weigh, on the average, about 250 lbs. per cubic yard. In Boston they weigh about 202 lbs. per cubic yard.

These rubbish collections have been divided as follows:

	By weight.	By volume.
Combustible material	60 per cent.	37 per cent.
Incombustible material (valueless).	5 " "	3 " "
Marketable material	35 " "	60 " "

The rubbish is picked over at the dumps by a trimming contractor, who pays the city for the privilege. The value of this marketable material to the city is about $3.20 per ton. The Commissioner of Street Cleaning has stated that this figure is too low; probably it should be increased 50 per cent. It is figured as follows: The average rubbish collections are 300 tons per day, or 1 800 tons per week, of which the marketable or salable material is 35%, say 600 tons. For this the contractor pays the city approximately $1 920, or at the rate of $3.20 per ton.

The present Commissioner of the Department of Street Cleaning had an incinerating plant* constructed, from designs by the speaker,

*Illustrated in *Engineering News* and in *The Engineering Record*, in April, 1902.

Mr. Parsons

at the city dump at the foot of West 47th Street, Borough of Manhattan.

The record of this incinerator is as follows: The number of loads of rubbish brought to the incinerator per day: Maximum, 80; minimum, 20; average, 44.2. The 44.2 loads per day weigh about 61 000 lbs., or 30.5 tons. Of this amount about 75%, or 22.87 tons, was consumed; 5%, or 1.5 tons, was incombustible; and about 20%, or 6.1 tons, was trimmed. Much more than 20% could have been trimmed, but the incinerator burned the material so fast that the contractor did not have time to separate it out.

The incinerator contains a grate surface of 90 sq. ft., and the stack is 120 ft. high. The average weight of the material consumed per hour is 5 720 lbs., or 63.5 lbs. per square foot of grate per hour.

The design of the incinerator, in brief, consists of three cells, each having 30 sq. ft. of grate area. The products of combustion pass over the cells into the smoke flue in such a manner that the product from Cell No. 1 has to pass over Cells Nos. 2 and 3; the product of combustion from Cell No. 2 mixes with the products from Cell No. 1 and together they pass over Cell No. 3; and that from Cell No. 3 mixes with the products from Cells Nos. 1 and 2 and is intimately mixed again in passing along a tortuous flue to the base of the stack. The result of this arrangement has been highly satisfactory, as regards the non-production of smoke. Taking a stormy day when the material was brought to the incinerator wet, the smoke was seldom visible for more than about 75 ft. from the top of the stack, and then only during the period of stoking one of the grates.

This incinerating plant was constructed as an experiment. In order that it might be free from any hindrance by injunction or otherwise, lest it create a nuisance to neighboring property, it was decided to locate the plant on one of the city piers, about 250 ft. from the bulkhead line. The permanency of location, of course, was not considered, the idea being that if the plant could be constructed quickly and show that combustion could be carried on without creating a nuisance, it would lead to the introduction in the future of other stations, more favorably situated, and at which better facilities could be provided for the reception of the material and for the picking of the same.

The incinerator, thus far, has proved satisfactory, and the Commissioner has authorized the preparation of plans for further developing its capacity.

An analysis of the cost of incineration compared with removal of material by scows is as follows:

First, the Final Disposition by Scows, as Formerly Practiced.—Assuming the same figures as now obtained at the incinerator, namely, 30½ tons of material per day, on the average, the cost of removal of that

material, figured at 15 cents for towing, and two days' hire of the scows (one for loading and one for towing) at 23 cents, comes to about 38 cents per ton. Owing to the bulkiness of rubbish, only about one-half tonnage can be put upon a scow, the tonnage being figured by volume, which makes the disposal of the material come to something like 80 cents or more per ton by weight. Therefore, 24.39 tons at 80 cents cost the city $19.51 for removal. The 6.1 tons, making up the 30.5 tons, which is saved by the trimmers, at $3.20, also figures $19.52; thus, practically, the cost of removal by scows was offset by the receipts from trimming. Mr. Parsons.

Second, by Incineration.—The result is approximately as follows: Received from trimming 6.1 tons at $3.20, $19.52 per day. Received from the city ash collections, which at this dump amount to about 600 tons per day, and which are made salable at, say, 5 cents per ton when freed from the rubbish, $30.00. Total receipts to the city, $49.52. The cost to remove the incombustible material, 1.5 tons, at 38 cents, 58 cents; cost of burning, interest and repairs on the incinerator, estimated, at $7 per day; labor, feeding and firing, four men, $10 a day; ash removal, $1 a day; total, $18. Net gain, therefore, to the city, $30.94 per day; yearly gain, more than $9 000.

The incinerator, at these figures, will pay for itself within two years. According to the figures quoted by the Commissioner, namely, 19 cents a ton for the ash collections, would make a daily revenue of $114 from the ashes, in place of $30, or a net gain of $114.94 per day, or more than $34 000 per annum; at which rate the incinerator would pay for itself in less than six months.

The ashes produced by the incinerator are very light, completely burned, and, owing to the large quantity of wood from which they are produced, have some value as a fertilizer, and are used by the Park Department for spreading on lawns and around trees.

The improvements referred to are an unloading floor and a belt conveyer, which should increase the amount of material trimmed, that is, the marketable material; and should reduce the cost of labor. Probably the services of two of the men now required could then be dispensed with.

The problem before a City Commissioner—to dispose of the refuse of a municipality—is not always a scientific one. Usually, he has to face a practical problem. In New York City, the fault is due to the form of government and the contract system now in vogue. As a change cannot be made quickly, one has to do the best he can.

The scientific treatments of the wastes of a municipality are fairly well understood. The question is one of engineering; and an engineer who is willing to study the problem can dispose of those wastes in a manner which will be sanitary, provided, of course, that the munici-

Mr. Parsons.

pality will give him, or will give the Commissioner, the money to carry out his plans.

The wastes are being disposed of in Europe in a more scientific manner than in this country. The reason, probably, is that action was taken in America without previous scientific study. In Europe, they started with cremation. In America, they followed with cremation; but, as the cremation system adopted was false, failure followed, and, in many localities, public sentiment was set against it. This has been probably the chief reason that cremation is not more generally adopted on this side of the Atlantic.

In Europe, the collections are made and brought to a destructor, where they are cremated; and, in the most successful plants, they are cremated without the use of any fuel whatsoever, beyond the fuel supplied in the garbage and by the other wastes. Each collection district differs in the amount and character of its refuse, but there is sufficient combustible material collected which, when mixed with the garbage, will make it burn in a satisfactory manner.

The object sought, in the most successful plants, is to produce a high temperature; and a plant that will not produce a high temperature is not considered successful.

An incinerator or crematory, as the destructors are called in this country, which has to have a fume or stench cremator, is false in design, or else has that element put into the design in order to meet public sentiment. If the temperature in the burning furnace is sufficiently high, there is no need of a fume cremator. A fume cremator is simply a small fire placed either at the base of the stack, or somewhere in the passage of the gases, the idea being to burn up any fume-creating particles that might pass from the furnace before they reach the outside air.

In Europe, recent practice has not adopted a high stack, many successful furnaces being operated with a short stack and a forced draught. By a short stack is meant one of 70 to 80 ft., although some are still lower. Sufficient height should be given the stack to stop any question as to its being a source of annoyance or a nuisance. The earliest destructors used very tall stacks and natural draught.

Personally, the speaker favors the destruction of municipal refuse by cremation, and believes that it will be generally adopted in this country before a great many years have passed. As indicated before, persons have promoted furnaces, destructors, cremators and incinerators which were not designed scientifically, or have formed companies not strong enough, financially, to carry out their claims. Several cities have recorded failure from both these causes, and in some the destructors are now out of use.

There has been another cause of failure, due to the collection of garbage at the destructor. Garbage, when allowed to collect *en masse*,

is extremely offensive; and, unless it is properly taken care of and promptly burned, is apt to create an adverse public sentiment, although the destructor itself may be good of its kind. Mr. Parsons.

The system of reduction has been adopted by a number of our larger cities because it was easier to organize a reduction plant than a destructor plant. The fear of creating a nuisance—one of the causes most frequently mentioned—has acted to delay progress in the direction of cremation. The same cause, however, was not as active in the case of reduction. The returns from a reduction plant are not sufficient to operate it. Such a plant must rely upon a bonus from the city. The returns from properly constructed destructors, supplied with suitable municipal wastes, should enable the plant to be more than self-maintaining, and to earn a handsome income for the municipality.

It is quite common in Europe to see small towns in which the actual pumping of the water supply is accomplished by means of the steam generated from the heat produced in the destructors. Some towns use the power for electric street-lighting, and others sell the electricity generated. It is perfectly possible to use the heat generated in a manner which will be income-earning, while the reduction plant needs to be sustained by a bonus.

Destructor plants will probably first be started by the smaller towns. On their success, which depends on proper engineering advice, the larger cities will slowly plan future improvements.

The practical problem in any city is the distance from the point of collection to the point of discharge of the carts. In some cities that haul is short, in others it is long. In New York City, some of the carts, the speaker believes, have hauls as long as five miles. A system of collection by automobiles has been discussed, but no automobile has yet been designed which would be sufficiently regular to stand the service. Perhaps, in time, such perfection may be reached as to warrant the collection by this means.

Snow-melting machines cannot handle the snow fast enough. If the carts could be regulated so that they would bring the supply just at the rated capacity of the machines, they might operate in a satisfactory manner; but the trouble is that all the carts arrive together. As they cannot stand in line with their loads of snow, they have to dump it, and if the machine cannot take it it is simply dumped on the street, which is just what is not wanted. When snow has lain in the street a little while, it becomes mixed with dirt and is then difficult to melt. Snow-melters have not proved economical, either in time or money.

If the snow is collected from the streets of New York City promptly, there is little objection to its being dumped in the river, as the snow is very clean. A great drawback has been the lack of docks from which snow could be dumped.

Mr. Parsons. While Mr. Soper's remarks are interesting, some of his statements scarcely give due weight to the practical conditions as they exist in the City of New York.

The speaker is sure that anyone studying the conditions as they exist in this city would conclude that the problem is less scientific than practical. In order to turn the practical problem into a scientific one requires time, and in time it will probably be done.

What all cities and all municipalities need is a co-operation between the different departments. The present Commissioner of the Department of Street Cleaning has done more than any other Commissioner in this direction. A Commissioner is hampered by the General City Government, of which he is but a part. The failure of some of the former administrations, to clean the streets and dispose of the refuse properly, may not have been due solely to the Commissioners.

No criticism of Mr. Soper's purpose is intended. His remarks seem to be misleading to members who have not made a specific study of the subject. His criticism of some of the former Commissioners is a little severe. While the results may have been as stated, it is possible that the Commissioners did not have the power to remedy those conditions.

The garbage of New York City contains an enormous amount of water, and the worst class of all to burn is the stuff collected from the fruit markets, as it is practically non-combustible, except by strong aids. Ordinary offal or kitchen garbage will burn reasonably well when mixed with the other wastes.

The rubbish collections in New York City are 95% combustible; the ashes from the private houses and small apartment houses contain about 20% of unburned coal. If the rubbish collections and the ash collections from private houses and small apartment houses are mixed with the garbage, the whole can be burned in a suitable furnace.

The ashes from the steam-heating companies and large manufacturing plants, known as "steam ash," are collected and brought to the dumps in separate vehicles, so that there is no necessity at any time of ever passing such ash through a destructor, because that ash is practically pure.

In Europe, the principal system of collection is one of non-separation. They simply collect the whole of the refuse, and this, just as it comes, goes into the destructor.

Most destructors contain some form of what is called a "drying table." The material as collected, either wet by contained moisture, or wet by rainfall, is placed first upon some part of the cell or furnace where it can be warmed, and is gradually passed back over the fire, in a manner similar to the coking method of firing. When the material

has become dry, it is forced back to the hottest part of the grate, where it burns rapidly, supplying heat to dry the incoming material, while sufficient heat is left to evaporate, in boilers, according to the material burned, from 1 to 2 lbs. of water per pound of refuse. Mr. Parsons.

W. F. Morse, Esq.—For twelve years the speaker has been actively engaged in the work of final disposal of municipal refuse. It has been his province to present the question in many places and in many ways, and, until now, it must be candidly said that it has not met with appreciation or attention on the part of the engineering fraternity. It has been a question which has fought its way, despite opposition, has been in the hands of men and committees who were really unacquainted with the subject, and, consequently, has been approached from the standpoint of an endeavor to solve an engineering question without the benefit of the best engineering skill. Mr. Morse.

The whole subject is a very wide one; it cannot be treated in a short way—by a short discussion—it has to be taken piecemeal and dissected, each part separated and treated by itself.

The remarks of Mr. Hering cover the whole question in a general way. He has given an outline of the various methods of collection, of the disposal, and of the results obtained. The remarks of the Commissioner of Street Cleaning and of Mr. Parsons cover the work done in New York, but there are many other cities than New York investigating this matter, and it is of much wider scope than the limited field of a single city.

In the limited time allowed it is possible to deal with the question only in a very general way, and to give a brief sketch of what has been done in the past ten or twelve years in this country, and, in comparison with that, an idea of what has been accomplished abroad.

Municipal waste has been divided into four classes: garbage, street sweepings, ashes and refuse. The disposal of all these is accomplished by two methods, or systems: reduction and cremation. Reduction, or the treatment of garbage only for obtaining a commercial product, is not now under discussion; but it may be said in passing that this method has been adopted by several of the larger cities, has cost large sums of money to establish, and is yet at a stage where it is impossible to say what its future will be. It is only known that companies and men are putting large sums of money into reduction processes, and that, so far, as many plants have failed and have been abandoned as have succeeded.

If a city is investigating this subject with a view to the disposal of all its waste, and if it adopts a means of disposal which treats only one-tenth of it, there is manifestly left on its hands the remaining nine-tenths. Reduction deals with only 10 or 12% of the whole collected waste of the city, treating garbage only. Cremation, on the other hand, takes the whole collection of miscellaneous waste and disposes of it all.

Mr. Morse. There have been in the United States, in the last twelve or thirteen years, something like seventy-five or eighty places where cremation has been adopted. This work was begun in Des Moines, Iowa, about fourteen years ago, by a furnace invented by Mr. Andrew Engle, and from which have come all the forms of the American cremator, all more or less imitations of the original Engle type. It is a structure of rectangular form, having an upper chamber and transverse bars on which the garbage is deposited. The fire is at one end, and in most cases the secondary fire for burning the gases is at the other end. In all cases of American crematories two fires have been found necessary, and that principle has been maintained in constructions of this type.

About a month ago, an article appeared in one of the prominent municipal journals under this caption: "Why do American Crematories Fail?" The text of that article was a report, made by a leading engineer of this Society, upon a furnace built in a neighboring city, and which was reported to be working unsatisfactorily. In the main essentials, that article is true, and, after twelve years' experience in building garbage furnaces in this country, the speaker is in a position to say that satisfactory progress has not been made; that while one or another type of furnace after the American pattern has been built and has performed its functions, and may be still doing so, the retrogression—that is to say the abandonment of furnaces which have been built after these patterns—has kept pace with the number installed. Therefore, comments, by the newspapers and by prominent engineers, to the effect that the progress of the disposition of waste in this country is not satisfactory, are absolutely true.

Beginning fourteen years ago, with that form of American cremator which was shortly after imitated by other constructions, there have been seventy-five built, and of these perhaps the most widely known and successful installation of the American type was made at the World's Fair in Chicago. This was a case where it was expected that some 50 or 60 tons of refuse per day would be handled, also the sewage sludge which could not be disposed of in any other way. Furnaces, after an improved Engel pattern, were built, and were run six months without intermission, using oil as fuel, and destroying on the grounds of the Exposition, within the confines of one building, all the garbage and all the sewage sludge caused by the presence of 27 500 000 persons, without sanitary nuisance, and to the entire satisfaction of the authorities.

That is an example of what might be done under the best conditions in which an American furnace could work, but that example was never improved upon. The furnaces so built were offered as a gift to the City of Chicago, but they were declined on the ground that they were placed on public property, under control of the State, not the City, and could not be accepted by the City. The results of that

demonstration in Chicago show that under proper conditions garbage containing a large percentage of moisture and sewage sludge (two of the most refractory things in the world to deal with by fire) could be destroyed by maintaining a sufficiently high temperature and providing combustion chambers for the destruction of the gases. Unfortunately, this example was never carried much further by that company, but it was acted upon by others, and has been repeated since; yet, in spite of the lessons taught by ten or twelve years of experiment, it may be said that the progress made in cremation work has been equalled by the retrogression in the same line; that furnaces are abandoned about as often as they are built. Mr. Morse.

There are several obvious reasons for this. The work has been begun at the wrong end. At the outset, a sufficient amount of engineering skill was never applied to it. Municipal committees have gone about the country and have been persuaded by ambitious furnace builders to install plants. These plants have been simply experimental—built for a profit. They were not durable, and required extensive repairs. In many cases they were not sanitary; they emitted odors; they were not in all respects adapted to the work required of them, and they were expensive to operate. Yet, with all their defects, they have made for progress in one particular: they have directed the attention of the people to the fact that something is needed.

At the present time there are four or five companies constructing garbage crematories with varying success in different parts of the country. There are at least ten or twelve firms who have gone down—in other words, who have constructed furnaces found to be inefficient—and we are at a stage of the general question of cremation where it is necessary to have some more efficient means brought forward. If progress is to be made, it must be made either by inventing a new furnace, or by adopting other furnaces which have been proven successful elsewhere.

The question arose in England twenty-five years ago, long before it was ever thought of here. It began by the construction of the cell furnace, so-called, the Fryer destructor, operating by the use of a natural chimney draught, no forced draught being thought necessary at that time. The results were almost identical with those of the American furnaces of to-day. The temperature was low, offensive gases were thrown off, notwithstanding the "fume-cremator," or secondary fire, and it was found expensive to maintain. No real progress was made until about four or five years ago, when the furnace was shortened, forced draught introduced, the sloping platform made in such a shape that the garbage could be used as part of the fuel, and a combustion chamber added, behind which a steam boiler was placed.

The English destructors are to-day one of the most powerful agencies for sanitary conditions in England. They take what is

Mr. Morse. known here as municipal waste, as a whole. No separation is made; the entire waste of the household goes into what is called an ashpit, or ashbin—garbage, refuse and ashes—and this is taken directly to the destructor and burned. It is destroyed under forced draught, with no other fuel needed than the material itself. The result is the production of a volume of heat which operates steam boilers of very great capacity, the power from them being utilized for the production of electricity, for pumping sewage and water, and for many other municipal purposes.

The comparison between English and American efficient disposal work is distinctly against us. We are doing as they did six or eight years ago. At the present time there is no English destructor on this continent. The Thackeray furnace is an attempt. It is really an imitation of the principles of the Fryer destructor which was built many years ago in England, and which has now almost passed out of date, being supplanted by more powerful ones. There are two examples of this furnace, one in Montreal and another in San Francisco; but in the last five years, since these furnaces were built, no others have been installed, and there has been little attempt to develop more fully the English ideas.

The chief reasons for this lie practically on the financial side of the question. The cost of the construction of a destructor is about one-half more than the cost of an American cremator of equal capacity, and municipalities are usually looking first to the dollar and second to the sanitary operation and to the comfort of the people.

The following figures are quoted from the latest information regarding the operation of the English destructors. The comparative results from twenty English destructors, of eight different types, with thirty-two tests made for evaporation at different periods, shows that the average combustion per square foot of grate surface is 47 lbs. of mixed waste, garbage, ashes and refuse, and the evaporation of 1.36 lbs. of water for every pound of waste consumed. Therein lies the secret of the progress made in England. When they put into their destructors a mixed mass of material, burn it under a forced draught, and develop steam power which is equivalent to the evaporation of 1¼ lbs. of water for every pound destroyed, the enormous force produced can readily be seen, the utilization of which has made it possible for every municipality to do its work with its own power, without other fuel than the material destroyed, at a very small cost as compared with the cost of operation on this side of the water.

The cost of labor for destroying a ton of mixed refuse will run from 12 to 30 cents per ton, dependent upon local conditions. In one place the work is carried on at a profit; in others, the returns from the destructor, in steam power and in products manufactured from ashes, pay all operating expenses and fixed charges. The

residuum from these furnaces is a valuable asset. The clinker is ground up and made into mortar, or tiles, paving blocks and brick. Mr. Morse.

There is another item on the credit side of the destructor, that is the utilization of power developed by the combustion of municipal waste for use in electricity works.

There are about 160 places in Great Britain in which destructors are used, and more than two-thirds of these utilize the power for various purposes. The electric force developed by a destructor which burns the waste products of a city is equivalent to 30 British Board of Trade Units per ton of waste destroyed. If it be assumed that each unit is equivalent to 280 candle-power, the result is something like 8 400 or 8 500 candle-power from each ton of waste.

The chief reason why advance in disposal work in that country has been so rapid and efficient is the fact that English municipalities proceed upon a different plan from ours. They make it a part of their municipal work. In this country it is contract work, and, consequently, there is not the same opportunity for cities to develop along the lines of municipal ownership and administration. There is a strong desire on the part of municipalities to adopt these improved methods, but they are held back by the fact that in almost every case the contract takes precedence, and the contractor is desirous only of getting through with his contract, and the same results are not accomplished as when the work is done by the municipality.

The remarks made by the Commissioner of Street Cleaning and by Mr. Parsons upon the work in New York City are pertinent and apropos of the question, but they do not cover the country. The principles which Dr. Woodbury is carrying out were instituted by Colonel Waring five or six years ago, and the experiments made at that time showed conclusively that the value of the rubbish of New York City was greater by far than anyone had supposed. The statement made by Colonel Waring in one of his last reports, that the value of the refuse, garbage and ashes of New York City would, if properly utilized, pay one-half of the total expense of cleaning the city, has never been realized. Yet it is certainly a question which is being answered by the present administration in a very satisfactory way. The Commissioner has alluded to, and Mr. Parsons has described, an incinerator, for the conversion of refuse, at West Forty-seventh Street.

The speaker had the honor of presenting this question to the Mayor of Boston four and a half years ago, proceeding largely upon the lines marked out by Colonel Waring, and at that time it was believed that the utilization of the refuse would become a feature of very great importance in municipal work. Mayor Quincy looked into the matter personally. He called for specifications and bids; he obtained four or five bids which were unsatisfactory, and rejected them. He took the plans which were offered for the construction of an incinerator in Boston,

Mr. Morse. and caused it to be erected by a private company. The incinerator is quite different in pattern from the one described by Mr. Parsons, but for four years it has been burning the refuse of the business section and a large part of the residential portion of the city, taking the waste from about 200 000 people, covering about 95 miles of streets, brought to one central point. The waste is carried into a room and dumped upon a moving platform, or belt, 150 ft. long, and during its passage the refuse is picked over by men placed on each side. These sorted portions pass into bins and presses below, and the remainder is discharged automatically into a destructor, or incinerator, placed across the end of the building. The quantity of waste destroyed began at about 25 tons per day for the first year, and it has increased until now about 40 tons per day are collected and disposed of. The product which is picked out from the refuse by these men will reach very nearly 60% of the whole bulk. It is divided into six or seven classes of paper, five kinds of rags, rubber, glass and iron. Everything possible is sorted out and saved, and the residuum destroyed are the small, worthless portions of paper, excelsior and straw, and a small amount of wood. The operation is conducted precisely as it should be conducted in New York City, in a closed building, the city carts discharging their loads out of sight of passers-by, no nuisance of any sort being connected with the work. After baling, the salable portions are at once conveyed to market, and the power produced by the combustion of the worthless portions of the refuse drives a 60 H.-P. boiler to its utmost capacity, which in turn moves all the machinery, lights the building with electric light, removes the ashes, heats the building in winter, and, thus far, has furnished a surplus of steam power.

The operation of this plant for four years shows that the refuse of a city of the size of Boston is more valuable than almost any other part of the municipal waste, and that every city with a population of 50 000 or upward can easily turn its refuse into money which will go a long way toward paying the expenses of the whole collection service.

Other cities are considering this question, with the idea of bringing into use a system similar to that which has been carried on in Boston, and which has just now been reinaugurated by the Commissioner of Street Cleaning in New York City, and which will undoubtedly be a factor in the disposal work of all cities in the country.

The average quantity of refuse collected is about 1 ton per day for every 10 000 persons. It may be more or less according to the different character of the city and the population, but it is of sufficient value to pay for the installation and operation of a plant in any one of the larger places in the country.

The future of this question depends upon utilization. American crematories have been going on for ten years, destroying garbage by

using coal. The builders, up to this time, have paid no attention to refuse and its salable and fuel qualities. They have allowed the heat produced by the combustion to go to waste; and they have not been over-desirous of guarding against sanitary nuisance, but have sought to destroy the waste in the shortest possible time, without considering the economical points involved. Mr. Morse.

There is a general impression that a change must be made before real progress can be had, and there is hope that the engineering profession throughout the country will take up this question, as has been done abroad, and bring its trained experience to the assistance of the municipalities, solving the question in a much shorter and easier way than it can otherwise be done. It is inevitable that this will come about. The men who are trained in constructive and operative work should be the ones to decide what shall be done in this line by every city.

There is another side to this matter which is pertinent to the question under discussion. That is the disposal of the waste of large isolated buildings, like public institutions of every class, hotels, business establishments and even individual dwellings. The quantity of waste produced in these places is proportionately larger than under other conditions. There is now in use a form of destructor, installed usually in the basement of the building, connected with the boiler breeching, or the chimney. These destructors are used for the disposition of every class of waste, including that from laboratories and medical colleges.

The latest examples of these furnaces have been built in connection with the steam boilers of large business establishments, where the heat from the enormous mass of waste destroyed is used as auxiliary for operating the boilers. In some cases the destructor is also provided with a separate steam boiler operated by the furnace, but supplied with its own fire-box, the power from which is utilized for specific purposes, like running elevators, or in connection with the low-pressure steam system of the building.

The advantages to be obtained by the introduction of these local destructors are the disposition of the waste on the premises in a perfectly sanitary manner without the necessity of storing and handling the same, and the development of a certain amount of steam power, resulting in the saving of coal, or other fuel, and to some extent expense in steam boiler equipment. These destructors are also being adopted by the Government for use in Army and Navy posts and government buildings throughout the country.

The number of these destructors in use, already quite large, is increasing rapidly, as the installations are made under the direct inspection and by the advice of competent architects and engineers engaged in the construction work.

Mr. Soper. GEORGE A. SOPER, Assoc. M. Am. Soc. C. E.—The question of the sanitary disposition of municipal wastes is often divided into two parts: Final disposition, and collection.

By final disposition is meant the utilization or simple deposit of wastes; and by collection is meant all other steps in the operations of a street-cleaning department. It is not uncommon, in discussions on this topic, to omit that part of the subject which relates to collection; but, as the two questions are inseparably related in practice, it seems desirable that they should be treated jointly.

To a large extent, the method chosen by a city for the final disposition of its refuse is a controlling factor in the organization and plant of its street-cleaning department. This has been so in New York City.

The history and development of the Department of Street Cleaning in New York City affords many interesting suggestions as to the relations between final disposition and collection, and the experience of that city furnishes, withal, such an instructive illustration of the need of keeping the various parts of the machinery of the street-cleaning department in harmony and up to the requirements of a rapidly growing municipality, that some extended reference to it may be useful.

The organization of the Street-Cleaning Department, as a separate branch of administration in New York City, dates from the year 1881, up to which time the collection and disposal of wastes was carried on under the direction of the Department of Police. The new organization was the outcome of much agitation on the part of the public; physicians and political reform associations taking an active part in the crusade.

For ten years after its formation the Department did little to justify its existence. On the contrary, it became such an object of dissatisfaction that, in 1891, it was determined to appoint an Advisory Commission to inquire into the defects of the organization and to recommend measures of improvement.

The Commission was named by Mayor Hugh J. Grant, and consisted of five citizens, among whom were two business men, a lawyer, a sanitary expert and an engineer, the last being a member of this Society.

The report of Mayor Grant's Commission marked an epoch in the history of the Street-Cleaning Department of New York City. It is, moreover, so remarkable a document, from the clear and exact way in which the faults and needs of street-cleaning departments in general are defined, that a summary of its findings is here given:

In the first place it was declared that the department was not efficiently managed, as judged by standards of management of well-established corporations engaged in large enterprises.

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One source of difficulty lay in the methods of employing labor. The laborers themselves were inefficient, and owed their positions to political influence.

The plant of the Department was poorly located.

The plant was insufficient.

There was a lack of proper organization and disposition of forces.

The manner of disposing of refuse was not satisfactory.

The law under which the Street-Cleaning Department was conducted was adequate, provided it was efficiently administered by a Commissioner who had the cordial co-operation of the Mayor, Police Justices, Department of Health, Commissioner of Public Works, and Board of Estimate and Apportionment.

The annual appropriation was insufficient.

The police should help to keep the streets clean.

There should be rules for the employment of men.

It was observed that the management of the Street-Cleaning Department required the same kind of ability as the management of a transportation company, or other large corporation employing a considerable number of men.

The report of Mayor Grant's Commission, one of the most forcible and lucid papers on this topic which the speaker has ever read, is the foundation upon which the present organization of the Street-Cleaning Department is based. The practical effect which the report had was a reorganization of the Department by legislative enactment in 1892.

Unfortunately, the opportunities thus opened for developing an efficient system of street cleaning were not at first realized. The first thing done in accordance with the recommendations was to increase the appropriations. Then progress ceased. The Department promised to remain as it had always been, an organization in which political influence was carefully and continually fostered.

By the time Mayor Strong's reform administration of 1895 came into power it was apparent that there was need of a strong head to develop the possibilities of improvement contemplated in the legislative act of reorganization. It is now a subject of universal satisfaction that such a head was found by Mayor Strong when, in 1895, he appointed the late Colonel George E. Waring, Jr., Commissioner of Street Cleaning. Whatever may be said of Waring's career, as an engineer or sanitary reformer, it must be admitted that in the three years during which he held office as Commissioner of Street Cleaning he made comparatively few mistakes and reached the greatest success, in raising the standard of usefulness of his Department, that New York City has ever known.

At the same time, it is not to be denied that circumstances favored Waring. A large part of his success was achieved on lines laid down

Mr. Soper. in the report of Mayor Grant's Commission of 1891. Waring also had the advantage of a report of a Legislative Committee of investigation and advice appointed by Mayor Gilroy in 1894. The report of Mayor Gilroy's Committee, dated November, 1894, recommends that:

First.—Dumping city refuse in the harbor or its tributary waters should be absolutely prohibited.

Second.—The ordinances requiring householders to keep separate the garbage, or kitchen refuse, from ashes and other house refuse should be rigidly enforced.

Third.—All house refuse should be collected in galvanized iron vessels with tight-fitting metal covers, of such size that, when full, they can be handled by one man.

Fourth.—Daily collections of garbage should be made by the City and delivered at dumping wharves into temporary storage, or self-propelled boats of some approved type to be furnished by the party having the contract with the City for the final disposition of the garbage.

Fifth.—The garbage should be disposed of by a reduction process producing fertilizer and commercial grease; and the City should invite competition by the various companies controlling such systems, in order that the greatest benefit to the City may result.

Sixth.—A separate collection should be made of the remainder of the refuse of the City "not otherwise provided for," which should be used for filling Riker's Island, or elsewhere; and, for transportation of this material, a sufficient number of self-propelled boats of approved type should be constructed and owned by the City. It should be provided, however, that whenever the whole, or any considerable portion, of the street sweepings can be disposed of by contract or sale for fertilizing purposes, at a price greater to the City than the value for filling, then such disposition should undoubtedly be made of them.

A careful reading of the foregoing recommendations will reveal on the one hand some excellent advice and on the other some stipulations which had the effect of committing the City to a particular process of garbage destruction and the plan of disposing of garbage by contract with a private company.

Some prominent reforms introduced by Waring were: Improved methods of administration; insistence that the laws and ordinances relating to cleanliness and order in the streets be enforced; and improvements in methods of collecting and disposing of the wastes. A large part of Waring's success, as the head of the Street-Cleaning Department, was due to his remarkable power of instilling a spirit of industry among his men. It has been well said that he found the force of sweepers and drivers a laughing-stock and left them a body of honored workmen.

Mr. Soper.

It is well known that, after reorganizing his working force, Waring's ambition was to devise means for the economical, if not profitable, final disposition of the City's refuse. Up to Waring's time, the ashes, paper, garbage, and other refuse of the city had been collected and carried in a mixed condition to points along the water front where it was picked over by Italians, who had the privilege of extracting bones, bottles, rags, metals, and other salable matter. This privilege was purchased from the City annually, and in 1894 amounted to $140 000. The residue left over after the picking was taken by scows and dumped at sea or used to fill in low lands in the neighborhood of the City.

Under Waring, the City wastes were separated, as is the custom to-day, into three classes before collection; notably, garbage, ashes and paper. Experimental studies were made of the value of these different kinds of refuse. Garbage was also collected from other cities, and the value of its grease and other constituents carefully determined. According to estimates, made at the time of these studies, the average quality of garbage produced in New York City was worth $2.47 per ton.

A practical plant for the separation of the utilizable ingredients of refuse, other than garbage, was erected and operated for many months. The sale of the bottles, metals, rags, paper, and other useful materials, thus collected from 31 300 tons of refuse, netted the City $3 680. A considerable amount of useful steam-power was also generated at the same time.

It is a lasting source of regret that Waring's term of office was too short to enable him to complete the development of a plant whereby all the wastes of the City could be disposed of profitably, or at least inoffensively. Just as his investigations were pointing to positive and permanent reforms his term ceased.

At the end of Waring's administration the efficiency of the Department immediately fell. The Commissioners who followed seem not to have been suited by talents or experience to conduct the Department on the plane of efficiency which Waring had initiated. Negligence, extravagance—some have said, corrupt practices—crept into the affairs of the Department. A single illustration will suffice to convey the speaker's meaning. The following extract is taken from page 24 of the Annual Report of the Department of Street Cleaning for 1900:

"In September, the New York Sanitary Utilization Company complained that it was not receiving all the garbage to which it was entitled by the terms of its contract with the City, on account of faulty separation, and claimed that the scow-trimming contractor was culling bones and grease for sale to which they, the New York S. U. Co., were entitled, and to which the scow-trimming contractor, by the terms of his contract with the City, expressly denied any claim or right. The matter was finally compromised by the Department paying to the scow-trimming contractor sixty cents per barrel for bones and one and three-

Mr. Soper. quarters cents per pound for grease collected from the ashes, which was turned over to the Sanitary Company. This arrangement resulted in a continual increase week by week in the quantity of this material collected from the ashes and street sweepings, so that for the last week in December the Department's payments to the scow-trimming contractor amounted to $2 127.41."

The charter of Greater New York, which went into effect in 1898, added much to the responsibility of the Street-Cleaning Commissioner, and complicated the unsolved problems of his imperfectly developed department. The plant of the Department should have been increased and the organization properly expanded to meet the requirements of the Greater City, but it is clear that no such logical development was contemplated.

The unsatisfactory condition of the streets of New York City at the beginning of the present administration is well known. Many of the innovations and improvements introduced under Waring were discontinued and forgotten. Much of the plant was out of order and some of it out of service. Two self-propelled refuse barges were laid up, apparently for no other reason than that they were too economical. Horses were out of condition, overworked, poorly cared for. The dumps and docks were in a disgracefully insanitary condition. The force of laborers was demoralized. The streets were filthy. The rules of the Department, and especially the City ordinances, were shamefully neglected. The policy of entering into contracts with private parties had been extended. The method of letting contracts was open to severest criticism. A contract for the disposal of the garbage of Manhattan had to be let at an exorbitant figure because bids were not called for until too late to secure profitable competition.

Were it not that commerce, convenience and health demand that the collection and disposal of the City wastes be carried on in an efficient manner, the great cost of the Department of Street Cleaning would furnish a sufficient reason why its work should be well done.

The City Budget for 1903 calls for an expenditure of nearly $5 400 000 to pay the running expenses of the Department of Street Cleaning. No other Department of the City Government, except the Departments of Police and Education, spend so much money. The annual cost of the Department of Street Cleaning exceeds the cost of many other Departments combined.

It may be profitable to consider for a moment the chief items of expense, as shown by the Annual Reports of the Commissioners of Street Cleaning:

First: Sweeping.—By this is meant the collection of dirt, etc., from the pavement. This item, in the year 1901, for Manhattan and the Bronx, amounted to $1 402 056.82.

Second: Cartage.—This includes the hauling of refuse material,

such as garbage, ashes, paper, and other like refuse. Carting, in 1901, in Manhattan and the Bronx, amounted to $990 577.71. Mr. Soper.

Third: Final Disposition.—This means the reduction of garbage by contract, dumping of ashes and other dry refuse to fill land, and sea dumping. In 1901, final disposition, for Manhattan and the Bronx, cost $733 602.01.

Fourth: The Removal of Snow and Ice from the Streets of Heaviest Traffic.—This item, in 1901, is said to have been about $600 000.

Fifth: Administration.—Administration cost $223 456.62, in Manhattan and the Bronx, in 1901.

Sixth: Rents and Contingencies.—For Manhattan and the Bronx, this item amounted to $121 490.07 in the year 1901.

The total sum represented by the foregoing items is $4 071 183.23.

From the reports of Mayor Grant's Commission, and the Commissioner of Street Cleaning for 1900, the expenses appear to have increased out of all proportion to the quantities of refuse removed. The figures are as follows:

Year.	Appropriation.	Loads of Refuse.
1882	$1 010 000	1 116 360
1890	1 280 525	1 702 102
1900	5 584 100	2 602 120

But the cost of the Street-Cleaning Department, as shown by the official reports, does not represent the total cost to the citizens for removing and disposing of the City's refuse. Other items of expense are the removal of dead animals from the streets, the removal of manure from stables, the removal of market refuse, the removal of cellar dirt, and the sprinkling of streets.

The largest extra is for private carting. An immense number of property holders employ private scavengers. Hotels, office buildings, apartment houses, restaurants, manufacturing establishments, retail dry goods shops, and many residences are compelled to remove their wastes at their own expense. Recently, even the privilege of the City dumps has been denied to cartmen, and it is said that in some cases refuse has had to be hauled several miles and carried across ferries for disposal.

The total expense of the extra scavenging work made necessary by the inability of the Street-Cleaning Department to collect and dispose of our municipal wastes in a satisfactory manner is very large. In 1891 the sum paid for the private collection of refuse was estimated to be between $150 000 and $175 000. It is now very much larger. The quantity of refuse of various kinds dumped at City wharves by private carts has been more than 30% of the total quantity collected by the Department of Street Cleaning. In addition, more than 100 tons of swill per day are carried out of town to be converted into soap, or fed to cattle and swine.

Mr. Soper. In reply to a request from the Board of Aldermen, for a specification or draft of the organization necessary to handle the output of refuse of the large office buildings, stores and places of business which now employ private scavengers, the Street-Cleaning Commissioner said, a few days ago, that he would require 500 additional horses, 500 carts, 500 drivers, 50 hostlers, three stable foremen, three assistant stable foremen, nine stable clerks, twenty stablemen, proper stabling for the horses, and spaces for the carts, together with such equipments as harness, blankets, buckets, etc., and proper water-front facilities for the handling of this material. The total number of carts and trucks now under the Commissioner, in Manhattan and the Bronx, is 744. By making his request for 500 more carts, the Commissioner tacitly admitted that 40% of the work of removing refuse in New York is now done by means outside of his Department and beyond his control.

The private collection of refuse is objectionable, from every point of view. It leads to insanitary practices, and is an item of expense and annoyance from which the taxpayers of the City should be free. The cost of private collection is not equitably distributed, but is often heaviest upon those who pay the largest taxes. But there is no use in emphasizing the evils and extravagances of the present situation. If the force, plant and organization of the Department of Street Cleaning were adequate to the needs of the City there would be no excuse for them.

If the foregoing remarks carry any clear idea, it must be that the work of collecting and disposing of the wastes of the metropolis is badly done. Such efficiency as exists is due largely to the energy of the present Commissioner and the effects of the two notable epochs in the history of the Department to which reference has been made. The first of these epochs was the investigation, report and reorganization due to Mayor Grant's Commission. To this may be added the investigation and the improvements suggested by the Committee of Advice appointed by Mayor Gilroy. The second epoch was marked by the tenure of office of Colonel Waring.

In the history of the Department, few, if any, important reforms or developments have been made which were not the result of seeking outside investigation and advice. Is it not time that the disposition of the City's wastes be again made the subject of an exhaustive inquiry?

At the present moment the City is deplorably dirty. Business men and property holders are complaining that their refuse is not removed, and an immense sum of money is being spent for the collection and removal of wastes which, upon theoretical considerations, are valuable. The Street-Cleaning Department is struggling under the disadvantages of an imcomplete and outgrown equipment. It may

seem like strong language, but it is not beyond the facts, to say that the system of cleaning the streets of the metropolis, if followed by a private corporation, would lead to bankruptcy. Mr. Soper.

The speaker intends no unfriendly criticism of Dr. Woodbury, our able Street-Cleaning Commissioner, in stating that the length of his term and the power of his office are not sufficient to enable him to correct, single-handed, the mistakes of the four years of mal-administration which preceded him, and place the Department on the efficient footing which the citizens have a right to expect. To meet the changed conditions due to the recent phenomenal growth of New York City, the Department needs to be developed, expanded and made as efficient as it was in Waring's time.

The speaker sees only one way by which these ends may be accomplished, and that is through the work of a Commission of Investigation and Advice, such as was appointed by Mayor Grant.

In the speaker's view, the most important specific problem pressing for solution is: How shall the City's wastes be finally disposed of? This is the keystone of the great question as to the best means of organizing and equipping the Department of Street Cleaning.

Second.—Another query is: Is it well for the City to enter into contracts with private individuals for horses and carts to collect the refuse, for barges to remove it to a distance and for reduction works to dispose of it?

Third.—One more question is: How can the ordinances relating to the careless littering of streets and the separation of refuse be enforced?

Fourth.—Finally: In what ways and to what extent should the plant of the Department be increased?

Without desiring to amplify this last interrogation unduly, or to presume to possess the knowledge required to answer it, the speaker would state that it is believed, by those who have taken an intelligent interest in the Department, that more and better dumps are needed; more and better scows are needed; more and better carts and horses and stables and stations are needed; and refuse destructors or garbage crematories, built in accordance with the best known practices, are needed. In addition, very possibly, street-sweeping machines and snow-melting machines are needed.

It should not be an open question whether mechanical devices cannot, to some extent at least, replace the hand labor which is now the chief item of expense in cleaning the streets.

The present moment is propitious for an investigation. The existing administration is pledged to municipal reforms, and has executed or planned several admirable lines of improvement. The present Street-Cleaning Commissioner has demonstrated, by a year's administration of his office, that he has the capacity, energy and determina-

Mr. Soper. tion to put in force such measures of relief and permanent improvement as may be placed within his reach. The work of the Commission which the speaker suggests would greatly facilitate his efforts to bring the plant and organization of the Department to a high state of efficiency.

It is a pleasure to say that the plan of appointing a Commission has received Dr. Woodbury's endorsement, and that Dr. Lederle, President of the Board of Health, has given it his approval.

Mr. Horton. THEODORE HORTON, Assoc. M. Am. Soc. C. E.—The Trenton garbage plant was a source of serious trouble during last summer (at a time, in general, when such plants give evidence of any defects in design or management), and a consulting engineer was called upon to investigate and make a report to the City in regard to it. He was asked, first, to determine the nature and extent of the trouble, and, secondly, to make such recommendations as might be needed to relieve the situation.

The details of the work, in a great measure, devolved upon the speaker, and he will describe briefly what occurred during his visit.

The plant, which, unfortunately, was located in the midst of a thickly settled district, consisted of two Davis destructors, connected with a stack 120 ft. high. Each furnace consisted of a combustion chamber; a drying chamber, below which was located an evaporating pan; secondary fire grates; a flue of somewhat contracted area leading to the chimney; and a set of screens to intercept dust particles.

The speaker spent the first day in familiarizing himself with the construction and operation of the plant, and in getting under headway a systematic record of the various features which would lead to a solution of the trouble. These consisted of a record of weights of garbage consumed, coal burned, and ashes; the times of delivery of garbage, charging of furnaces, firing, cleaning grates, operating dampers, and such other observations as might throw light upon the causes of the trouble.

While these records were being kept by the various employees of the plant, other observations, of a special nature, were carried on under the speaker's personal supervision. Thus, he made several analyses of the garbage, which in this particular case was a very important element, due to the fact that it was that known as kitchen garbage, or swill, and was free from ashes. At that season of the year, it was practically saturated. These analyses were simple, and consisted of merely assorting samples, of about ½ ton each, into various parts and weighing them. The garbage was found to consist of 84% animal and vegetable matter, 12% paper, 3% rags, carpets, etc., and 1% boxes, barrels and other rubbish; 80% of the whole being water.

Other observations were made to determine the extent of the

trouble arising from the dust particles which, emanating from the stack, were causes of much annoyance to the residents of the neighborhood, and of alleged fires in the immediate vicinity of the crematory. Mr. Horton.

The observations made during the daytime were simple in nature, but served at least to give a tangible idea of the actual conditions. They consisted of observing, at various distances from the crematory, and in the line of smoke from the stack, the number of particles passing a vertical plane in a given time. The distances selected were $\frac{1}{4}$, $\frac{1}{3}$ and $\frac{1}{2}$ mile, and the interval of time 15 minutes. The particles were from $\frac{1}{8}$ to 1 in. equivalent diameter, and of course were plainly visible.

In order to present this source of trouble in a still different light, other observations were made by selecting places in the open fields, at various distances from the crematory, and counting the number of particles deposited on an area of 50 sq. ft. During both the foregoing sets of observations, which covered a period of about 3 hours, the wind had been blowing steadily from the same quarter, so that, considered as a whole, the record really had a comparative value, notwithstanding its approximate nature.

In order to get some idea of the danger caused by these dust particles as regards the alleged fires in the vicinity, observations were made upon the glowing embers emitted from the stack at night. Thus, it was observed that:

First.—No embers were seen in a state of actual flaming.

Second.—Glowing embers were emitted principally at times when the furnace doors were open for firing, raking or cleaning.

Third.—During these times it was estimated that, on an average, 50 to 100 sparks were emitted per minute. Of these, it was estimated that 50% did not travel, in a glowing state, further than 25 ft. from the top of the stack; 90% not more than 50 ft.; 95% not more than 75 ft.; 99% not more than 100 ft. and an occasional spark from 150 to 200 ft.

In studying the question of internal combustion in the furnaces, other observations were made, to supplement the general record kept by the employees. These, however, were mostly of a superficial nature and hardly admitted of any refinement, except, perhaps, a determination of the temperature of the flue gases, and even this was somewhat approximate. The speaker had suspected that the temperatures were very low, and at first had tried 500° mercurial thermometers, but, after breaking two of these, and not being able to obtain a pyrometer, he resorted to the somewhat crude method of exposing in the flues metals having different melting points. By a system of elimination, these experiments indicated a temperature of between 800 and 900°, which was sufficiently close for the desired purpose.

Mr. Horton. At the end of the week's run, the foregoing records were tabulated and studied, and the following is a summary of the results:

RESULTS OF OPERATION OF GARBAGE CREMATORY AT TRENTON, N. J., FOR THE WEEK OF AUGUST 4TH–9TH, INCLUSIVE, 1902.

Total garbage burned	188.0 tons.
Garbage burned per day	31.3 "
Coal used on main fires	10.7 "
Coal used on auxiliary fires (estimated)	3.0 "
Total coal used	13.7 "
Coal used per day	2.3 "
Garbage burned per ton of coal	13.8 "
Approximate average time of burning each day	14.0 hours.
Equivalent number of days of 24 hours	3.5 days.
Equivalent garbage burned per square foot of grate area, per day of 24 hours	1 080 lbs.
Equivalent amount of garbage burned per cell of 25 sq. ft., per day of 24 hours	13.5 tons.
Estimated total amount of clinkers from garbage and coal grates	14.0 "
Estimated amount of ashes from below grates	3.0 "
Estimated total amount of ashes and clinkers	17.0 "
Percentage of ashes and clinkers to garbage burned	9.1 per cent.
Range of temperature of flue gases in stack	600°–1 000° Fahr.
Percentage of moisture in garbage	81.0 per cent.
Corresponding water evaporated daily in furnaces	25.5 tons.
Quantity of coal required per day to evaporate this water, on a basis of 10 lbs. of water per pound of coal	2 5 "

A discussion of all the questions involved in the investigation of this plant has been embodied in the report of the consulting engineer, and as this has already been published elsewhere in full, the speaker will give merely a brief abstract of the conclusions reached and the recommendations made to the City, as follows:

"1.—Notwithstanding the existing defects and the criticisms which it has been necessary to make, the Trenton furnaces belong to the better class of such plants in our country, and the troubles and nuisances with which you are now contending, are also more or less common elsewhere.

"2.—The collection in well-constructed metal carts, such as you have, and also the frequency of your collections, are quite satisfactory. It may be suggested, however, that provisions for thorough cleaning of the carts after dumping would be a still further improvement.

"3.—To obviate the nuisances of dust escaping at the stack, either from well-burned or unburned garbage, it is necessary, after securing perfect combustion, to introduce a dust-settling chamber of proper

size between the furnaces and the stack, containing baffles and properly placed inlets and outlets. The screens now in the chimney, although useful as a safeguard against accidental emissions of light but large matter, are insufficient to retain all of the matter now escaping from the furnaces. Mr. Horton.

"4.—To reduce further the possibility of unburned particles escaping through the stack, it is important to place dampers in the flues leading from each furnace, as well as in the chimney, so as to afford control of the drafts at all points where and when it is needed.

"5.—The garbage now delivered, when properly drained and carefully burned in a well-designed furnace, is readily combustible, and should not require the addition of as much coal as now used; and at some seasons, except to start fires, and, otherwise, on rare occasions, perhaps no coal may be required.

"6.—We find that the furnaces are not sufficient in size to effect a complete destruction of the material during the hours of the day when the crematory is operated. Continuous firing for 24 hours can relieve this sufficiently. To this end it would be necessary to store the material for a part of the day, and this could not be objectionable in any way.

"7.—To secure a complete combustion of the garbage, more economically than at present, the design of the furnaces should be somewhat altered. The horizontal grates are not the most suitable for the material, which must first be dried, and then with difficulty pulled from one position to another for burning. A sloping grate for burning, and a sloping floor for the drying chamber, from which the material can be gradually and almost automatically moved from the feed-hole to the hottest portion of the fire, permit of a better utilization of the heat, and reduce the difficulties of stoking.

"These recommendations, supplemented by a systematic attention and skillful practice on the part of the Superintendent and his subordinates, would enable them to operate the crematory so that nuisances from odors and dust would cease."

W. J. Baldwin, M. Am. Soc. C. E.—The speaker is wholly unprepared to talk on the subject of garbage cremation, for the reason that such cremation as he has been doing has been in another direction, *viz.*, either hospital refuse destruction, or waste fuel utilization. Mr. Baldwin.

Mr. Soper has suggested the matter of snow melting. There is a great deal of fun in the subject of snow melting, and, were it not that reference to it had been made, the speaker might refrain from alluding to it. The subject is very old, and should be well understood by engineers; still, it comes up, as in the present instance.

When Inspector Williams was made Commissioner of Street Cleaning of New York City, the *Sun* asked why he could not melt the snow off the streets over night, and not leave it to be shovelled and carted when the contractor got ready; and suggested the use of the fire engines of New York for this purpose. Of course, a technical paper would hardly propose such a thing, but Inspector Williams was exercised so much that he asked the speaker if there was anything in the suggestion. The speaker went to Professor Draper, of the Mete-

Mr. Baldwin.

orological Department, and ascertained the amount of the snowfall for a certain storm in New York City, and then calculated the street areas, not including the housetops or back yards. A computation showed that it would take all the fire engines in New York City, running day and night, three years to burn coal sufficient to melt that snowfall; that there would be 90 000 tons of coal to haul, and 20 000 loads of ashes left to cart away. The *Sun* would not publish this information, but it appeared in *The American Machinist*. Later, an experiment was made by Mr. Waring, in melting snow, in a manhole in the street, with a coil of pipe and a boiler, which showed the futility of such methods.

Experiences similar to these—steam-heated snow-ploughs, etc.—should set at rest the question of melting the snow, especially with steam, or even with direct fire. The computations were made on the supposition that all the steam generated could be brought in contact with the snow; but, as a matter of fact, in trying to melt snow by any kind of pans, or by blowing steam through it, probably not 10% of the steam would come in contact with the snow, and, in consequence, it would blow away. Again, evaporation will take heat not required for melting. It requires 142 B. T. U. to melt 1 lb. of snow from snow at 32° to water at 32°; but it requires more heat when the snow has a temperature of zero, additional heat to warm the water so that it will not freeze in running off, and heat—a great deal of heat—to vaporize the proportion of the water that will be vaporized.

In regard to particles, or sparks, that appear at the head of a chimney of a crematory, especially at night, they always appear as though they were luminous from heat, but investigation has proved that they were not always so; that immediately over the chimney these particles reflected the light of the chimney, and even when they passed a long distance—probably 20 ft. outside of the axis of the chimney—they would look as if they were afire; whereas, as a matter of fact, it was only the reflected light from the chimney. In an investigation leading to a determination of how far the sparks might fly, it was found that they were not actually sparks at all.

Again, there is the question of what might be done in the way of quenching sparks, assuming that they are sparks. With a chimney 100 ft. high, and having 1 000° of heat, there is a considerable upward push, which might be represented by 2 or 3 ins. of water pressure, and it is possible that something might be arranged at the top of such a chimney by which the sparks, smoke and gases could be given a slight dip into a water tank and thereby cooled.

Mr. Parsons has said that he thought this crematory or destructor could be made to operate without extra fuel. The speaker does not think this would be possible, as there is more than 80% of water in the vegetable and animal matter in garbage. A cabbage will

contain more; and all ordinary albuminous compounds—meats and other refuse—contain so much water that the speaker cannot see how it is possible to do without the use of some fuel. Mr. Hering says that the water is evaporated first, or that the moisture is drained off in channels before the garbage is put upon the fire, and is then mixed with a large quantity of dry refuse—wood, straw, paper, etc.—and also a large quantity of unburned coal. Mr. Baldwin.

In that case, the solution seems to be that there is enough carbon present to evaporate the water, but still, in many cases, there is a great deal of water after the ordinary draining and drying is done. An ordinary dry cabbage contains 80% of water, and the water is very hard to destroy, but, of course, it is necessary to take all the material that comes from hotels and from kitchens, as that is what is to be destroyed. Now, the speaker is satisfied that what is collected in separate receptacles as garbage, in New York City, would contain 80% of water which would not run out by gravitation, and that about 10% of the original would have to be good carbon in order to evaporate the contained water.

The speaker would like to see an apparatus which will burn the ordinary garbage and admixture with dry refuse, or even with ashes. The ashes from an ordinary engineer's department amount to about 20%, by weight, of the coal put in the furnace, but in those ashes there is not 2% of coal. Now, there may be wood enough, in some cases, but, even in New York City, where will the necessary quantity come from ?

The speaker can show drawings and furnaces constructed for special work—not primarily for destroying garbage, except in a general way—but is interested in the construction of crematories, and would like to know more about the way to construct a furnace and get along without a primary fire and the addition of fuel.

Another point about cremating garbage, and the utilization of the heat therefrom under boilers, is the formation of various vapors, or gases, which are partially condensable when they strike the heating surface of a boiler. They may contain acids which will injure the boiler tubes to a considerable extent; and, in Europe, where they utilize the heat under boilers, presumably, the boilers are of a very simple type. It would be well for anyone who desires to utilize the heat from garbage and general refuse crematories to study the effect of such gases on the small tube boilers used so extensively in America.

CHARLES B. BALL, M. Am. Soc. C. E.—There are two inquiries which seem to be pertinent to this subject. One is the question as to how far it is safe and desirable to use street sweepings as material for filling. The second relates to precautions to be observed in handling builders' refuse resulting from the demolition of dwellings which have been for a long time in an infected condition. Mr. Ball.

Mr. Ball.

THE USE OF STREET SWEEPINGS FOR FILLING.

The division of municipal refuse into four classes, as used by Mr. Hering:

I.—Ashes;
II.—Street sweepings;
III.—Dry rubbish;
IV.—Kitchen garbage;

is a convenient one for the present purpose. It should be remembered that only in exceptional cases are street sweepings collected separately, the usual method being to mix them, as found convenient, with any other class of refuse.

Premises.—To make clear the proposition advanced by the speaker, let it be assumed, at the outset, that kitchen garbage alone ought not to be used as material for filling low grounds, and that all mixtures of garbage with either ashes, street sweepings or dry rubbish are objectionable for this use to the degree in which they contain the more putrescible ingredients; also, that under some conditions ashes, and sometimes dry rubbish, may be utilized in this manner without danger.

The inquiry, then, is thus formulated: Whether street sweepings alone, or mixtures with ashes or dry rubbish, into which they enter as a principal element, are not undesirable materials for filling in low lands, parks and streets? It seems that this use of sweepings ought to be questioned, for three reasons: First, because of the considerable percentage of organic matter which they contain; second, because of the disease germs which are present in them; third, because of their objectionable physical qualities.

Prevalence of this Method of Disposition.—In connection with the general statements in Mr. Hering's opening discussion, that the use of sweepings for filling low land is a common one, certain data in *The Engineering Record* of November 29th, 1890, are of value. In a tabulated statement giving returns from seventy-eight cities and towns, as to the method of disposition of street dirt—which, doubtless, includes rubbish as well as sweepings—it is stated that fifty-four of these municipalities (69%) used such materials "for filling low places and private lands, or for grading streets and park grounds."

From the more comprehensive statement summarized by A. Prescott Folwell,* M. Am Soc. C. E., from the detailed reports obtained for the "Municipal Year Book for 1902," it is learned that 741 of the cities and towns having a population in excess of 3 000 report that street sweepings are used for filling. This number is 76% of those that report upon the method of disposal. It may also be noted that the Department of Street Cleaning of the City of New York advertises that:

"Persons having lands or places in the vicinity of New York Bay to fill in, can procure, free of charge, material for that purpose—ashes, street sweepings, etc.—collected by the Department of Street Cleaning."

* *Engineering News*, November 20th, 1902.

Mr. Ball.

Quantity.—Although few statistics are obtainable as to the total quantity of street sweepings handled by municipal authorities, the ratio which the refuse thus classified bears to the total quantity collected is ascertainable for some of the larger cities, as well as the quantities of sweepings collected by them.

In a table prepared for the Advisory Commission to Mayor Hugh J. Grant, and published in its report in 1891, the percentage distribution of the refuse collected in New York City in the years 1882–1890, is stated to be:

Ashes	about 62 per cent.
Garbage	12 "
Ice and snow	2 "
Street sweepings	24 "

The statement made by Mr. Parsons is that the distribution by volume is:

Ashes	57 per cent.
Rubbish	25 "
Garbage	18 "

There appears to be no difficulty in harmonizing these statements, it being understood that street sweepings and rubbish are included in a single item, and that the garbage constituent may often include many kinds of waste which, in a strict analysis, should be classified as rubbish rather than garbage. The latter table, by Mr. Parsons, showing the *per capita* distribution of the refuse in Greater New York, gives about 18% by weight of street sweepings. From these, and other less complete data, it would seem probable that 20% of the total amount of refuse represents well the proportion of such material in cities where the collection is made in well-defined classes, or that, at all events, such a percentage is not too large.

The report of the operations of the Department of Street Cleaning for the year 1900, which is the latest obtainable, states that it collected from all of Greater New York, 2 307 594 cartloads of "ashes, street sweepings and other refuse," apart from the item of garbage, separately named.

Composition of Sweepings.—The composition of street sweepings varies greatly with the character of the pavements from which they are gathered, with the method of sweeping—whether by hand or machine—and with the effectiveness of the separate collections of dry rubbish, such as dust, leaves, rags, paper, metal, old leather, straw, wood, glass, etc.

Organic Constituents.—It is obvious that sweepings from smooth, impervious, elastic pavements will contain much greater percentages of organic matter than such as are collected from macadam or rough stone pavements.

The limits indicated by Baumeister* are 4% for macadam pavements to 23% for stone pavements, and 60% for wooden pavements.

* "Cleaning and Sewerage of Cities," 1891 edition, p. 177.

Mr. Ball. An analysis of street dirt made in 1874 by Professor Edwin Waller, for the Health Department of the City of New York, gave, for an average of thirteen samples:

Water	3.032	per cent.
Organic and volatile matters	28.454	"
Nitrogen	0.369	"
Mineral	68.514	"

There appears to be no evidence to determine whether rubbish was or was not included in the samples for this analysis.

Examinations of the percentage of moisture, ash and organic and volatile constituents found in samples of ashes, sewer dirt, street sweepings and rubbish collected in New York City on two different dates, March 14th and May 1st, 1902, give percentages of the organic constituents varying from 17.86 to 40.70. The average of five analyses for each of the above dates was 26.31% of organic and volatile matters. The samples were collected by the skilled chemist who made the analysis, and garbage was excluded.

The prevalence, at the present date, of sheet-asphalt for street surfaces, as well as the constant increase in the ratio of paved to unpaved streets, would be likely to indicate that a higher percentage of organic matter is common, and it would seem that an estimated percentage of organic matter in sweepings at least as high as 35% would be justified.

Rubbish Constituents.—If street-cleaning machines are used instead of hand-sweeping methods, the resulting refuse will contain a smaller quantity of miscellaneous rubbish, as the sweepers and shovelers in the latter case collect from the gutters various articles of small dry rubbish which the machines do not touch. Most of these materials, such as leaves, paper, straw and hay, are light and combustible, but considerable quantities of waste metals, glass, crockery, plaster, etc., are heavy and incombustible.

Germ Constituents.—In addition to the tuberculosis germs noted by Mr. Hering as being abundant in street dirt, the bacilli of diphtheria are by no means uncommon, and typhoid fever germs are sometimes found.

A series of experiments was conducted by the Street-Cleaning Department of the City of New York in August, 1902, by exposing Agar plates, at the curb level and 6 ft. above, in various locations distributed over the city, and noting the number of colonies of bacilli developed during a stated period. The isolation of specific pathogenic germs was not attempted, to any considerable extent, the object being to determine the varied effect of different kinds of traffic in distributing the bacteria in air; but a maximum of 30 colonies per inch-minute was found in the east-side tenement district, and a minimum of 0.06 colony for a suburban street in the Bronx.

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The important question respecting the danger from these bacilli is that of their viability.

It is now well known that the tubercule bacillus retains its life properties for long periods when dry, but it is not so well demonstrated that it is dangerous when in a moist condition, such as would occur most frequently beneath the surface of a fill. Respecting the life of the typhoid and diphtheria bacilli, there appears to be no doubt that these are perpetuated in damp surroundings.

Professor Charles Harrington, in his "Manual of Practical Hygiene" (1901), discussing the function of the air as a carrier of infection (pages 226–230), summarizes the extensive researches of Dr. Eduardo Germano on the permanence of typhoid with the statement that "this germ as well as that of diphtheria can live for a long time in moist surroundings."

G. Lister Sutcliffe, in an introductory chapter in his "Sanitary Fittings and Plumbing" (1901), says:

"Dr. Sidney Martin's experiments with the typhoid bacillus, for example, prove that it soon dies in 'virgin' soils, whether these are sandy or peaty, but that it rapidly multiplies in moist sterilized samples of soils from gardens and other cultivated places, and retains its viability and vegetative properties for months and perhaps years. Moist sterilized soil which had been impregnated with the typhoid bacillus was found to contain the bacillus at the end of 450 days. The soil was then naturally dried for 49 days, till it 'could be readily powdered into a fine dust;' the bacillus was still there.

* * * * * * * *

"The lessons to be learnt from these and other investigations are that some pathogenic organisms are not by any means so short lived as is commonly supposed, that they may spread rapidly under suitable conditions, and that they may exist for a considerable time even in dust so dry as to be blown about by the wind."

Physical Characteristics.—It is evident that the physical qualities of permanence and stability, required in ground to be used for foundations of structures, or even for the sub-surface of streets and parks, are lacking in street sweepings, owing to the considerable quantity of organic matter and light combustible material contained.

Conclusions.—That the opinions expressed by the speaker are not altogether new, is shown by a paper on "City Scavengering at Boston," read by Eliot C. Clarke, M. Am. Soc. C. E., at the meeting of the Metropolitan Public Health Association in Nashville, Tenn., on November 18th, 1879. The work of scavengering is here classified as constituting four parts:

1.—Removal of offal;

2.—Removal of ashes and house dirt;

3.—Cleaning of streets and street basins;

4.—Cleaning of privy vaults and cesspools.

Under the second division of his subject, Mr. Clarke writes:

"A large part of Boston being very low land, there is great temptation to use this refuse (ashes and house dirt), in the place of earth filling,

Mr. Ball. and such is its usual disposition. If the ashes were perfectly free from admixture with other substances, it would form suitable filling for most purposes, but it is not so."

He then explains the attempts to keep out objectionable rubbish, and, in the following statement, summarizes the failure to accomplish this:

"On an average, nearly one-third of each cart-load of so-called ashes consists of other refuse. Portions of this refuse are harmless enough, as, for instance, broken glass, crockery, plaster, old iron and tinware, but other portions entirely destroy the suitability for filling, such as bones, hair, leather, rubber, paper, pieces of cloth and carpeting, old baskets, and, in short, any vegetable or animal matters liable to decompose. The ashes and house dirt are used to grade streets and parks belonging to the city, and private lands, when desired or permitted by the owner. In a few cases a small sum is paid to the city for the filling. It is evident that the presence of the refuse house dirt renders ashes undesirable for street building, as the matter, as a whole, compacts very slowly, and continues to settle for years. If the surface be paved or covered with gravel, there will probably be no smell; but digging trenches for laying gas and water pipes, sewers and drains, will be an offensive operation for a number of years, since organic matters, kept from a free supply of oxygen, decompose slowly.

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"It is probably a serious mistake to dump house dirt on land which is to be built upon. It is true that the organic matter mixed with the ashes must in time disappear; but how soon, it is impossible to say. Excavations made in Boston in land filled from city carts ten years previous have disclosed remnants of organic matter, and the process of decomposition is still going on. The risk in living over such land may be slight, but, however slight, it is a risk of disease and death."

In considering the third division of the subject, he writes:

"Forty-eight thousand and fifty-nine (48 059) cart-loads of dirt (street sweepings) of 40 cu. ft. each, were collected during the past year (1878?), and were disposed of in the same manner as ashes and house dirt, by being used to fill land for streets, parks and dwelling lots. The street dirt is of a rather uniform character, consisting of earth, road detritus, fragments of wood, leaves, paper, soot, hair, etc. Under exceptional conditions, from well-paved streets in the heart of the city, a load is sometimes obtained of sufficient manurial value to fetch a small price for use on land, but this is seldom. It is a manifestly unfit substance for filling, both from an engineering and from a sanitary point of view; but what else to do with it is a problem yet unsolved."

To the speaker, the solution appears to be a clear one, in view of the statement by Mr. Parsons, that "rubbish collections are very combustible, as are also street sweepings." The conclusion appears to be incontestable that street sweepings may and should be burned, irrespective of the question whether they can or can not be made to assist in disposing of the more objectionable garbage.

THE DEMOLITION OF INFECTED DWELLINGS. Mr. Ball.

It has been recognized for some years by students of sanitary science that human habitations in which filthy conditions prevail for a long time become so infected with disease germs that no cure can be effected. Although the recent methods of disinfection by formaldehyde gas are to a degree effective, it seems questionable whether even those will render safe for habitation a dwelling which has for a long time been permeated with disease and filth.

Danger of Infection.—The report of the Tenement House Committee of 1894 (usually called the Gilder Commission, from R. W. Gilder, its Chairman), makes a brief reference to their conclusions in this regard, as follows:

"It is a well-known fact that human dwellings, by prolonged occupation, become so saturated with the bodily emanations of those who have lived in them, sick and well, as to be less healthy than newer houses. It has often been proposed to construct hospitals of flimsy and inexpensive material, after the manner of a temporary shelter, and destroy them by fire every few years, to be replaced with new ones.

"This result of prolonged human occupancy is made worse in this city by the rapidity with which the character of the population in the lower parts of the city has changed, and the fact that houses built as private dwellings are not fitted to serve as tenements, either in respect to light, ventilation, water supply, privacy or facilities for cleanliness."

Respecting the fact of tuberculosis infection in old houses, there is no higher authority than Arthur R. Guerard, M. D., of New York City. In a paper presented to the Tenement House Commission, November 16th, 1900, treating of "The Relation of Tuberculosis to the Tenement House Problem," he says:

"It has been repeatedly observed that some houses in overcrowded districts after a time seem to become permanently infected with tuberculosis, as evidenced by a repetition of cases of the disease. * * * It is easy to understand how the permanent infection of premises may occur when one considers that the sputum of consumptives, which frequently contains a countless number of virulent tubercle bacilli, is often carelessly expectorated on the floor and elsewhere in dwellings, where it dries and is converted into dust, thus getting into cracks in the woodwork, in the papering, etc., whence it is later inhaled into the lungs by others. Such tuberculous dust has been found by experiment to remain virulent and infectious for months and even years after it was deposited in rooms which were not thoroughly disinfected and renovated; and where this dust is allowed to accumulate for a length of time it may be impossible to disinfect and renovate the premises without practically rebuilding them. These premises then become permanently infected."

John F. J. Sykes, M. D., in his recent book on Public Health and Housing, thus refers (pages 82 and 83) to the dangers of infection:

"Miquel, Emmerich, Carnelly, Haldane, Anderson, Johnstone and other observers and experimenters have shown that with the in-

Mr. Ball. creasing use and age of a dwelling-house the walls and spaces beneath floors become liable to harbour micro-organisms to an increasing degree. The more the surfaces, especially the floors and walls of a house, become worn and defective, the better lodgment they present for the accumulation of organic matter—the nidus of micro-organisms—and the less attention paid to repair and redecoration, the more unhealthy the influence of the house becomes.

"All these experiments and observations indicate the necessity for such construction, maintenance, and usage as best conduce to the cleanliness and purity of the air in and around dwelling-houses, in order not only to prevent disease, but also to prevent the loss of that vitality, vigour, and energy which cannot easily be measured by experiments or by statistics."

The conclusions of these various investigators as to the danger in the use of such dwellings, appear to the speaker to justify reasonable precautions in their demolition, and in the handling of the materials, both the valuable and the useless, resulting from this tearing down.

The number of buildings for which demolition permits were issued in 1902 by the Bureau of Buildings, Borough of Manhattan, Greater New York, was 1 622. This number, it is well understood, does not represent all the buildings demolished, as a small proportion is torn down without the formality of a permit. If this list is examined by anyone conversant with the city, he will note, from the street locations, that certain of these demolished dwellings are very old buildings in tenement districts, and in some cases such as were not constructed originally for tenement purposes. A search of the records of these buildings will show that they are infected with disease, and have been for a long period in unclean condition.

Present Method of Demolition.—The present method of demolition results in the removal, for fuel purposes, by the poor of the neighborhood, of the smaller portions of the wooden floors, casings, roof, etc., which are then stored in the adjoining cellars. It results from this that a building infected with disease germs, filth and vermin, may readily disperse these dangerous elements in the vicinity.

The only supervision of a sanitary nature over the practice of demolition in New York City at the present time is the requirement by the Department of Health that frequent sprinkling with water shall be given to the walls as they are torn down, in order to avoid objectionable dust.

Desirable Precautions.—It would seem to the speaker desirable to examine all buildings, about to be demolished, as to their sanitary condition, and, if this is found to be at all doubtful, to observe the following precautions in their destruction: First, that the building should be kept constantly wet with a disinfecting solution as the work of tearing down proceeds. From what has been stated already, it is evident that the old paper on walls and ceilings, the plaster of walls, and the woodwork of the floors, doors and trim of the rooms and halls are the elements of danger. These should be sprayed thoroughly at the

commencement of the work, and kept wet. The Building Code of the City of New York requires the demolition of buildings to be carried on story by story, and the systematic execution of the work as indicated herein would be facilitated by the adoption of this rule in all cases. Mr. Ball.

Second, that no combustible material should be distributed in the neighborhood, but that it should all be removed, and that which is valuable for fuel only thus used under conditions which would prevent the danger of contagion. The old paper, lath, floors, doors and trim of the rooms should be burned in some locality remote from any residence, and, by the use of simple gratings, will furnish fuel for the incineration of much of the light refuse.

Third, that any portions of the structure which are suitable for use in new buildings should not be used thus without having been subjected to suitable disinfecting processes.

Fourth, that, during the process of further excavation of the site, the soil removed should be examined as to polluting matters, and, if found to contain such, it should be treated with disinfectants. The actual demolition of old tenements in New York City, with the excavations for cellars of new buildings, shows that, where school sinks and earthenware house drains have existed, there is an extended saturation of the soil. The removal and proper treatment of this saturated soil is a matter of great importance.

Fifth, that all non-combustible waste refuse should be kept under supervision, as to the method of disposal. Where it is impracticable to treat any waste material by some process of sterilization, the disposal should be at some locality not likely to be used, even in the remote future, for residence or business purposes.

M. N. Baker, Esq.—It is very evident from the discussions that refuse disposal is a distinctively engineering problem; but, thus far, in America, it has rarely been recognized as such. It is to be hoped that the time is coming—in fact, that it has arrived—when there will be a much needed change, in this respect. There are, in this country, connected with the various companies who are building garbage furnaces or who are establishing reduction plants, comparatively few engineers engaged in the work. Mr. Baker.

It is a significant fact that, whereas our municipalities call in eminent engineers and spend money unstintedly for water supply and sewerage, only on one or two occasions have they called in an engineer to advise them in the matter of garbage disposal, and as far as entrusting to an engineer the whole problem of refuse collection and disposal it is doubtful whether a single instance could be named.

There is the valuable report on the Trenton investigation, mentioned by Mr. Horton, but it is yet to be heard that there have been any decided practical results from it. But, at Trenton, no engineer was called upon until after several years of blundering upon the

Mr. Baker.

subject; and, bad as Trenton is, as an example of neglect in this respect, it still remains a shining example of almost the only city in the country that has secured any engineering advice whatever.

One of the cities to adopt garbage cremation recently is Milwaukee. The contract for installing the furnaces provided that the contractor should guarantee that they could be operated with eighteen men, but it is stated that there are 79 or 80 on the pay roll at the present time. It is claimed that this is no fault of the furnaces, being a mere matter of affording employment to municipal laborers; but, however that may be, it serves as an illustration of the unsatisfactory condition of garbage disposal in this country, and of the need of employing engineers to design and operate garbage disposal works.

The low temperature in the Trenton furnaces is remarkable. In recent English installations the aim is to get as nearly as possible to a temperature of 1 800 or 2 000° Fahr., instead of 800 to 1 000 degrees.

Some interesting letters have appeared recently in the London *Electrician*—letters brought out by a paper* by W. F. Goodrich, Assoc. Inst. Mech. E., on a combination of refuse destructors (as they call them in England) and electricity works. Several of the writers of these letters, men in some instances who are operating combined refuse destructors and electricity works, have expressed themselves strongly in opposition to such a combination. Certainly, such opposition is a significant fact, and one that should be considered very carefully at the inception of garbage disposal as an engineering problem in this country.

Thus far in the discussion, comparatively little has been said regarding reduction as a means of garbage disposal. To present the subject fairly would take much time, but attention may be called to a fact which, perhaps, has already been mentioned, but only incidentally, that in all, or nearly all, the larger cities of the United States, which have any improved means of garbage disposal whatever, reduction is being used, and scarcely any of them are using cremation.

This does not necessarily imply that reduction in this country has been eminently successful and cremation has been a failure, but the figures do show that reduction is at least worthy of serious attention. All the reduction plants are in the hands of private companies, and comparatively little satisfactory information regarding their financial success is available. Possibly before this discussion is closed it might be feasible to bring out some detailed information from persons familiar with reduction systems. Unquestionably, such information would add very materially to the value of this discussion, in which the many large reduction plants of the country have been virtually ignored.

* "Electricity from Refuse—The Case for the Modern Destructor." A paper read before the Manchester Local Section of the Institution of Electrical Engineers, and published in abstract in *The Electrician* for November 28th, 1902. The letters mentioned appeared in the issues of the same journal for December 5th and 19th, 1902.

CITIES OF THE UNITED STATES, HAVING POPULATIONS OF 200 000 OR MORE, WHERE IMPROVED METHODS OF GARBAGE DISPOSAL ARE USED. Mr. Baker.

	Population.	Improved means of disposal.
New York	3 437 202	Reduction.
Chicago	1 698 575	None.*
Philadelphia	1 293 697	Reduction.
St. Louis	575 238	Reduction.
Boston	560 892	Reduction.
Baltimore	508 957	None.†
Cleveland	381 768	Reduction.
Buffalo	352 387	Reduction.
San Francisco	342 782	Cremation.
Cincinnati	325 902	Reduction.
Pittsburg	321 615	Reduction.
New Orleans	287 104	None.
Detroit	285 704	Reduction.
Milwaukee	285 315	Cremation.
District of Columbia	278 718	Reduction.
Newark	246 070	None.*
Jersey City	206 433	None.
Louisville	204 731	Cremation.
Minneapolis	202 718	Cremation.

Statistics, in the above table, collected by the speaker for his "Municipal Year Book," and revised to date, show that, of the nineteen cities of the United States having populations of 200 000 inhabitants or more in 1900, fourteen have some improved means of disposal, and, of these fourteen, ten depend on reduction and four on cremation. In addition, two other places have awarded contracts for final disposal, with the understanding that reduction will be used. Even if the list be extended to include places of 100 000 inhabitants or more, having improved means of disposal, there are but six with furnaces to fourteen with reduction plants, or sixteen of the latter if plants under contract are included. Taking into consideration all places of 3 000 population and more, there were, in 1902, a total of 74 crematories and 22 reduction works, all but three of the latter being in places of more than 40 000 population. Reduction is generally held to be impracticable in small cities, but the figures given show that in the United States that system prevails wherever it is feasible.

ELMER W. FIRTH, Jun. Am. Soc. C. E. (by letter).—The use of public dumping places within the city limits is an important phase of refuse disposal as applied to New York City. In the Borough of Brooklyn, for instance, there are deposited at these places, not only Mr. Firth.

* A small quantity of garbage is, or has been, cremated.
† Contract awarded, with the understanding that reduction will be used.

Mr. Firth. ashes, but the dust and dirt gathered from public and private buildings and conveyances, the soiled sawdust from wooden cuspidors, street sweepings, and much garbage and other refuse. Much of this deposit is subsequently blown about the streets in the vicinity, and the Health Department has received many complaints as to the frightening of horses, and other unpleasant experiences resulting from flying papers, etc., from these dumps.

The transportation of such large material suggests a greater distribution of dust and dirt through the air in these localities, and, possibly, an increased morbidity or mortality due to this condition. Figuring the average diphtherial death-rate in Brooklyn, by wards, from statistics in the Health Department reports for 1895 and 1896, it was observed that this death-rate was higher in the vicinity of the public dumping grounds than in other sections of the city. The writer hesitates to mention this as more than a coincidence, admitting that the relative number of cases of sickness would be a better basis for comparison. Then, also, it may be said that as these dumping places are generally located in the poorer sections of the city, scanty or inefficient medical service would increase the number of fatal cases in these localities; but against this argument may be placed municipal supervision, quarantine and the free distribution of anti-toxine.

It should be noted that in diphtheria the seat of infection is in the respiratory passages. The bacillus recognized as its cause withstands prolonged drying, and may be carried through air in a virulent condition. While it is not claimed that this specific disease is transmitted directly by the dust blown about from these deposits of refuse, yet a predisposition to it may result from inhaling constantly such impure air.

Even if the deposition of such refuse is not proved to be accountable directly for much of the suffering in these places, it at least maintains an unsanitary condition in the very communities where the death-rate is highest and in the midst of classes least capable of avoiding infection or of curing disease.

Mr. Falk. Myron S. Falk, Jun. Am. Soc. C. E. (by letter).—Many and various have been the methods proposed for the sanitary disposal of municipal refuse. The complete destruction of the material, by means of heat generated by itself or by the aid of heat supplied from extraneous sources, has been the method most advocated. The first case brings into consideration the hope that power may be obtained from this waste material at the time of its destruction. In relation to this, and during this discussion, the plan of producing gas, and thus, indirectly, power, immediately from municipal wastes has not been considered; it is possible that mature reflection may reveal great inherent advantages to be derived from this method of disposal.

In the production of gas, as is well known, water in the form of

steam is added to the gases produced from the destructive distillation of coal. It seems not at all unreasonable, therefore, in view of the large percentage of moisture contained in garbage, to expect that the introduction of garbage into a gas producer may not only be a direct saving in the fuel required, but may also obviate the necessity of adding live steam. It is true that, in the ordinary case of gas production, it is steam and not wet fuel which is added, but it is not unreasonable to expect that some method can be devised by which garbage may be placed in the producer at such times and in such a manner that its contained water may replace the water which must ordinarily be added. There is but little cause to doubt that such a plan may be put in successful operation, and it certainly seems to offer as great a possibility of obtaining power from wastes as any other plan heretofore proposed. Mr. Falk.

CHARLES H. HASWELL, M. Am. Soc. C. E. (by letter).—The introduction of water into towns and cities for domestic and public services, other than that obtained from public and private wells, involves the laying of pipes for its reception and transmission, and of sewers for its discharge in combination with the excrementitious matter of their residents and animals, the filth of hospitals, households, slaughter-houses, stables, manufactories, tanneries, street washings, etc. The resultant of this flow is the pollution of the earth or water over or into which it is discharged. Mr. Haswell.

The disposal of crude sewage and its treatment, the mitigating of its septic elements, its sanitary, useful and effective disposal, combined with the resulting pollution of the rivers into which it is discharged, and the insanitary effects thereof, is becoming a subject so important, as relates to the existence and duration of human and animal life, that it imperatively demands immediate consideration and action. It is of more national importance than the aggregation of all the financial and political questions of the time; yet, with the exception of the consideration and report of the St. Louis Commission on the Chicago Drainage Canal, and possibly some other isolated cases, it is criminally neglected.

Primary Disposal.—In internal villages or small towns it is customary and quite practical to mix the excreta with earth, bear it beyond the residences of inhabitants, and use it for fertilization, or deposit it in masses and cover it with earth. In the more populous towns of Europe, trenches are excavated and filled, the ground selected being suitable for infiltration of the fluids of the sewage reservoirs and cesspools, and being located at a proper distance from residences. When filled, these trenches are covered with earth, the surface of their contents, meanwhile, being exposed to evaporation, and their whole contents to infiltration (their masonry being open-jointed); but when the earth in which they are placed is clay, wet or saturated, or is con-

Mr. Haswell. tiguous to a stream of potable water, they are constructed with close joints, and, periodically, their contents are pumped out and distributed for fertilization.

Treatment.—In order to mitigate the noxious exhalations of crude sewage, it is, in some instances, delivered into tanks, reservoirs or coke-beds, for aeration, subsidence, filtration and oxidation.

Chemical Purification and Precipitation.—Chemical purification is effected by a strong mixture of lime, salts, sulphur, oxidizing compounds, etc., with the crude sewage. Iron and aluminum salts, if followed by lime, give a purified effluent.* Precipitation is effected by the use of lime in solution, and by sulphate of alumina. In populous towns and cities, any like treatment of their sewage, in consequence of its volume, is wholly impracticable.

Surface Precipitation.—This involves the occupation of a large area of land, it being officially estimated at one acre for every hundred of human inhabitants.

In the course of purification, oxidation is an essential portion of the changes through which sewage has to pass. Sedimentation or subsidence of the solid and dense material of sewage is claimed to arrest pollution; if so, the effect is retroactive, as it would result in the gradual filling up of the bed of the river, by the formation of foul and noxious shoals. The natural purification of water, to the very slight extent to which it is attainable, is effected by the combination of ammonia, arising from the mixture of decomposed animal matter, with the oxygen of the atmosphere.

Filtration.—In order to arrest bacteria and organic matter by this process, sewage is delivered into reservoirs and subjected to the absorbent capacity of coke and sand; which operation involves the frequent cleaning or replacing of these materials, as their absorbent capacity will soon become inoperative on account of the arrest of the dense particles of the sewage.

Infiltration.—Infiltration is classed by Rideal under three divisions as Broad, Intermittent, and Mixed.

Broad.—In broad infiltration, the sewage is distributed over large surfaces of agricultural land, or sewage farms, as they are termed, on which it is purified. This method involves the occupation of very large areas of land, officially estimated, like that of precipitation, at one acre per hundred of population.

Intermittent.—This is effected by the deposit of sewage at short intervals of time, on an area of porous earth as restricted as will absorb it, but making the products of vegetation of secondary importance.

Mixed.—In the mixed system, the sewage is first purified by sedimentation or by chemical means. The efficiency of this operation

*Samuel Rideal, D. Sc., London. John Wiley & Sons, N. Y.

depends wholly upon the character of the soil, as to its porosity and freedom from water, saturation, clay, peat, or conglomerated gravel. The Local Government Board of England prescribes for stiff clay one acre for every twenty-five human inhabitants, and for loamy gravel one acre for every one hundred. Mr. Haswell.

Cremation.—Cremation is effected by the evaporation and the combustion of the crude sewage at a very high temperature, a forced draught in the furnace, and a very high chimney to dispel the noxious effluvia of the combustion. In the operation of some furnaces in England, it was essayed to prove that sludge (precipitated and dense sewage), both remuneratively and without offence, could be incinerated, and that the coke produced paid for the operation. It was found, however, that the agricultural value of the residuum was so much impaired that it could not be disposed of profitably for that purpose. The evaporation of the liquid, and the combustion of the sludge requires the consumption of some fuel. When the sludge is submitted to a filtering pressure, an average of 7.74 tons (2 240 lbs.) per million United States gallons of crude sewage is obtained. At Southampton, England, it was essayed to burn sludge remuneratively, and without noxious results. The combustion of coal was first used to try it, the ammonia evolved was collected and the volatile matter was passed through the fire. It was claimed that the value of the coke produced paid for the cost and expenses, and that the net cost of the combustion and incineration was inconsiderable. In support of this operation, it is to be considered that even where sewage is discharged into bays upon the sea coast and below the confluence of the tidal and river flows, the velocity of the ebb tide is not wholly effective in transporting it to the ocean, as it will subside in slack water, and in the basins (locally and erroneously termed slips) formed by the projection of piers, thus creating noxious exhalations, and causing frequent dredging and the transportation of their contents to the ocean.

Fluid Discharge and River Pollution.—Where towns and cities are located on a long river, and above the extreme line of confluence and commixture of its water with the tidal water of the ocean, as some on the Hudson, Delaware and Connecticut in the East, and on the Ohio, Illinois, Mississippi and Missouri in the West, the pollution of the water by the discharge of crude sewage into it is increased progressively by the discharge from other and adjoining towns, but somewhat mitigated by the gradual addition of water from tributary streams (which, however, will eventually become polluted in like manner), down to the point of its confluence with the water of the ocean.

Effect of Pollution.—It is generally, if not universally, claimed that foul or polluted water purifies itself; and, in support of this claim, tests and observations have been made. Thus, the Massachusetts Board of Health deduced that if the crude sewage was less than 0.0077

Mr. Haswell. ($\frac{1}{130}$) of the water of a river into which it was discharged it would not affect the water objectionably. In other words, it is advanced that if one measure of crude sewage is mixed with 130 measures of river water in its normal condition it would yet be potable, notwithstanding that its septic or putrefying quality would not be negatived or eliminated. Further, an investigator in Europe has declared that if the crude sewage does not exceed 0.066 ($\frac{1}{16}$) or 6.7% of the river water, when it flows with velocity equal to that of the sewage, it would not affect the potable quality of the water; notwithstanding that, in addition thereto, all streams and rivers are polluted more or less by the rain washings from farmyards, roads, decayed vegetable matter and the putrefaction of dead animals.

As to the distance in which crude sewage discharged into a flowing river will become innocuous by the alleged self-purification of the water, authorities differ, as one puts it at 25 miles and another at 200. The desirability of assigning any general distance, assuming it practicable to do so, is negatived by the point of location at which any putrescent matter was present. Thus, a putrefying carcass of an animal, by its gravity (for instance, that of a dog with a weight attached to it), may remain at the bottom of a river. Over this the water would flow, and receive putrescent matter from it for a long time.

While it is conceded that pure water is only chemically obtained, in a laboratory, natural water is acceptable for domestic requirements, provided it is free from noxious matter, and is not offensive to taste or injurious to health and commercial requirements.

Notwithstanding the popular declaration that even crude sewage, discharged in flowing water, will, when mixed with it, in various assumed and empirical proportions and assigned distances of flow, become potable, a knowledge of the various impurities of such polluted water is not pleasing to reflection. The riparian inhabitants of the river into which the sewage of a populous city flows are passively subjected to the drinking of its water of pollution, yet, at the same time, they will consider the presence of any, even slight, impurity in their other fluids or foods, as milk, mineral waters, flour, meats, fruits, etc., as objectionable and not to be submitted to passively. As to the "self-purification" of water, it is difficult to manifest how the many and various chemical, vegetable and animal pollutions can be eliminated from polluted water by any process, physical or chemical, and unless they are eliminated, the assertion that water will purify itself is a common and grievous error, and, despite the claims of chemists and scientists of all grades, they are challenged to manifest in what manner, chemical or self-acting, water infused with excrementitious matter, the discharge of tanneries and slaughter-houses, paint, ink and glue factories, hospitals of all kinds, dead bodies of men, animals and fish, can be made acceptably palatable. A whole is an aggregation of

its parts, and if a volume of foreign or offensive matter, however small, is introduced into pure water, its purity is negatived. Mr. Haswell.

Insanitary Effects.—Living animals cannot retain health while the discharged products of their vital action are permitted to be retained about them, and when they are confined in that condition death gradually ensues. The result of a sanitary disposal of fluids is illustrated in the improvement of the health of towns by the reduction of their death rate. An instance is the City of Leeds, England, where, in twenty years, the death rate was reduced from 28 to 18 per thousand of its inhabitants.

In towns and cities where infiltration is wholly depended upon for the disposal of sewage, the soil becomes contaminated with fæcal matter, which, undergoing but little oxidation and in combination with the periodical cleaning out of the cess-pools or reservoirs, renders the exhalations therefrom both noxiously offensive and insanitary. In the country and in some small towns it is customary to avail of streams over which to set privies, and when the streams are sluggish the fæcal matter will subside in its flow and pollute the earth to an extent affecting its sanitary condition.

Reviewing, then, the elements submitted, it is presented:

1st.—That for internal villages and small towns, sewage can be readily disposed of by infiltration in and the fertilization of the adjoining soil.

2d.—That for similarly situated and larger towns and small cities, while the sewage can be infiltrated to a serviceable extent and the solid portion used for fertilization, yet the area of soil required for effectual operation is so great as to render this method generally, if not wholly, impracticable.

3d.—That from all locations, from villages to populous cities, on tidal rivers or sea coasts, up to the clearly defined limits of the tidal flow or confluence with the fresh-water flow, their sewage may be discharged directly in its crude condition, as instanced in the sea-bound cities of Boston, New York, etc., Burlington on the Delaware, etc.

4th.—That if the discharge of sewage, crude or treated, into our rivers is continued, it will wholly arrest them from being resorted to for the supply of potable water, and supplies must be obtained from the ponds and lakes with which our country abounds. Animal life cannot exist in polluted water, and the cost of arresting its pollution, in view of its result, is not to be considered. As the health of our people is of primary importance, the emergency must be faced.

5th.—That to draw upon the waters of Lake Michigan and its northern tributaries for the service of the Chicago Drainage Canal and the mitigation of its pollution of the rivers into which it is discharged, and by assigning a given volume of it, *pro rata* with the number of popu-

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Mr. Haswell. lation of the City of Chicago, would result in the lowering of the surface levels, and all adjoining waters down to the Gulf of St. Lawrence, and be prejudicial to both the manufacturing and commercial districts of all the intervening towns, as a consequence of which it would not be permitted, either by the Government of the United States or that of Canada. Hence the proposal is utterly impracticable of adoption, as its effects would soon become so insupportable to the people of both countries that they would arise in opposition, and Congress would be appealed to for relief, and damages be claimed.

6th.—As the sewage of populous towns and cities cannot be disposed of effectually, or with sanitary requirements, either by evaporation, precipitation, filtration, or its discharge into rivers above the line of commixture of tidal and fresh waters, or into lakes, or by mixture with great proportional volumes of water from our lakes, with immunity from the pollution of the potable waters thereof, there are but two methods left, viz., one for populous inland towns and cities, the sewage of which must be chemically discharged of its noxious exhalations and disposed of for fertilization, if practicable to do so; and the other by cremation, in which there is no danger of the pollution of water supplies, or insanitary effects. To operate it, involves the construction and maintenance of a furnace plant, and that the sewage, as received, must be as free from surface fluids as practicable, and that where sewers for the reception and conveyance of both sewage and surface water exist, as in large cities, independent drains be laid for the surface water.

7th.—That, great as this combined cost of reconstruction and construction would be, it is so inconsiderable, compared with the beneficial results to be attained by it, that the expenditure is not to be entertained as a bar to the method, for the result of the discharge of the water of our rivers above the line of commixture given will soon have to be faced squarely, as the destruction of the potability of the water of all rivers bordered by populous towns or cities will become eventually so extensive that it will interfere with the requirements of the people and of their horses and cattle. It will also cause the destruction of the fish, and how it is that the citizens of Chicago entertain the opinion that the operation of their drainage canal will be submitted to, and that the riparian residents of the rivers into which its sewage is discharged will submit to it passively, is wholly inexplicable to the writer.

8th.—That the discharge of sewage, crude or treated in any antiseptic manner, in a fresh-water river, is offensive, noxious and not to be entertained with any regard whatever to the sanitary requirements of its riparian residents; that it will not be submitted to; and any or all towns or cities contributing to the pollution of such water will not only not be permitted to continue in such practice, but will

inexorably be required to dispose of their sewage in some other and proper manner. Mr. Haswell.

9th.—That existing wells, for households, in densely populated towns and cities should be filled up and abandoned forthwith, and the vaults of all privies and tanning vats made water-tight, to arrest infiltration of any part of their contents to contiguous and subterranean watercourses, and to guard against the result of the ignorance and indifference of some people who disregard all sanitary requirements and permit the proximity of privies to their wells.

Finally, when this subject of the disposal of sewage is entertained in a proper manner, and such disposal is operated under sanitary requirements, the wonder will be how and why it was that any of the now existing methods, including the very restricted operation of cremation, for populous inland towns and cities, were tolerated.

W. H. Booth, M. Am. Soc. C. E. (by letter).—The sole reason why cremation of garbage has been a success in England is that it is burned in ovens and not near boilers; that is to say, the cells in which it is destroyed are wholly of firebrick, and only when combustion is complete are the products brought into contact with the comparatively cold plates of a steam boiler. Mr. Booth.

There is really no very serious difficulty in completely destroying refuse at a high temperature, as a simple calculation will show. Anyone who has a garden knows that ordinary garden rubbish, leaves, etc., will destroy itself if heaped up high above a small quantity of dry stuff. The initially dry stuff dries out the wet stuff which lies upon it, and this then burns and the whole heap is dried off and burned.

In England all refuse is collected together, *i. e.*, not separately, and includes ordinary house refuse, such as cinders and vegetable refuse. It is considered that this material contains 30% of water, 30% of combustible matter and 40% of inert matter, such as gravel, broken crockery and clinkers or ashes.

As carbon contains 14 647 B. T. U. per pound, 1 lb. of average refuse will contain 4 400 B. T. U. At 1 500° Fahr., the water will carry off less than 550 B. T. U., including latent heat and superheat. There will remain 3 950 B. T. U., to deal with. Allowing 18 lbs. of air per pound of fuel, there will be 54 lbs. of air, 0.3 lb. of fuel and 0.4 lb. of mineral matter to be heated up to a temperature of, say, 1 500°, or a total of 6.1 lbs. to share in 3 850 B. T. U., or 631 units per pound. The mean specific heat of all furnace products and clinker, etc., is less than 0.25. Calling it 0.25, the resultant temperature would be 2 524° Fahr., or 631 × 4, which is sufficiently above 1 500° to allow for further excess of air. Moreover, as the air forms by far the larger weight of stuff passing through the furnace, it becomes a simple matter to add considerably to the temperature by heating the air in the flues beyond the destructor.

The reduction of temperature, due to the increase of specific heat

Mr. Booth. of gases at high temperatures, need not be discussed. It will not pull down the temperature below 1 500 degrees.

The combustible elements in any refuse can be ascertained easily by having a bulk sample weighed and burned off in a gas retort, after being first dried, and again weighed, the second difference being combustible. If a refuse is so poor that it has not sufficient fuel in it to burn thoroughly, it ought to be mixed with the cheapest grade of coal obtainable and all burned together in a refractory cell. The placing of a boiler as one boundary of a destructor cell is the worst possible practice. Even good bituminous coal cannot be destroyed by such a device without smell and fumes.

The sloping grate, of course, is a great aid to the work, for the labor then consists only in helping forward the clinkered purified residue. The heat carried off by the water is partly recovered when the gases are passed finally through a boiler; but no sanitary engineer now attempts to use the heat from a destructor until destruction is complete and nothing but glowing gas remains. A simple calculation for any ordinary sample of refuse will show that it has power to heat up everything it contains to a clear red heat or higher.

Mr. Young. H. A. YOUNG, Jun. Am. Soc. C. E. (by letter).—Mr. Parsons has made the statement that "an incinerator, * * * which has to have a fume or stench cremator, is false in design," etc. The writer believes this statement to be entirely correct. Such a crematory should be condemned at the outset. If proper combustion is obtained, no fume cremator will be required.

In the best forms of the English crematories, there is always a combustion chamber. The gases evolved by the burning garbage pass first into this chamber after leaving the furnace. Here fresh air is supplied, furnishing oxygen for the almost complete consumption of the obnoxious gases. The temperature in this chamber rises higher than that in the furnace proper.

From the combustion chamber the hot air and gases, resulting from a practically complete combustion, are carried under the inclined drying plane, thus drying the "green" garbage from the bottom to the top of the pile, and not merely the upper layer. From here the flues continue under the boilers and to the chimney.

In many of the best types the flues pass through an additional chamber, in which is installed a blower, driven by power furnished by the boilers. The draught is thus induced, and there is no danger of forcing burning particles out of the chimney.

Mr. Hering. RUDOLPH HERING, M. Am. Soc. C. E. (by letter.)—The discussion has revealed a fair unanimity of opinion regarding the fact that the garbage question has now reached a point where its proper solution requires the aid of the engineering profession, instead of being left for solution almost wholly to committees of city councils or of boards of health. It is also apparently agreed that different conditions demand

different methods of disposal, and that each municipality should select the method which, after a careful study of the specific local conditions and a careful investigation of the cost of securing unobjectionable results, proves to be most economical. Mr. Hering.

It is further agreed that the problem must include a consideration of the methods and cost of handling all of the several kinds of refuse between the points of origin on the streets and the points of final disposal.

When opening the subject, its largeness precluded entering into details, but a number of these have been elaborated subsequently, and have added valuable information.

In reply to Mr. Baldwin the writer may state that there are at least three garbage furnaces in America, where, it is said, all the refuse is burned without the regular addition of coal, excepting to start the fires on Monday mornings, or whenever they have been interrupted. One is in Montreal, where the garbage is mixed with dry refuse and with domestic ashes, which, however, are screened at some seasons, if not always. Another is in San Francisco, where there is a similar furnace and where the garbage is likewise mixed with dry rubbish and ashes. The third is in Atlanta, Ga., where the garbage and dry rubbish alone are burned, and no domestic ashes, with the residuum of unburned coal, are added.

The writer was glad to hear from Mr. Parsons that his investigation had convinced him that the garbage and refuse in New York City, when mixed, would be self-combustible. Steam ashes, being the result of intelligent and economical firing, have no fuel value left, and always should be removed separately and utilized for filling, road-making, or as the body-material of mortar. But domestic ashes, containing 20% of unburned coal, have a fuel value beyond the cost of screening out the fine ashes, which value may be sufficiently great to utilize. Whether or not such utilization is economical, depends on the extra length of haul to the crematory, and on the cost of screening.

It would be very interesting and useful if the precise facts leading up to Mr. Parsons' conclusion could be made public. Generally, he intimates, the scientific treatment of garbage is fairly understood and could be put into practice, provided the means were available. But this understanding is not the only requisite for a solution of the present difficulties. It is also necessary that the public should appreciate it fully and have confidence in the recommendations, because the public must furnish the means to carry them out. To this end, an actual demonstration on a practical scale seems to be the *sine qua non*, showing that the treatment which engineers, after studying the special problem, believe to be the proper one, will be both successful and economical. Such a demonstration is yet lacking in our own country.

Most of the present disposal works were proposed by promoters, who succeeded in obtaining contracts to erect plants, and whose

Mr. Hering. interest lies chiefly in immediate profit to themselves. An impartial and thorough investigation, in order to ascertain the best methods and results for ultimate instead of for immediate profit has not yet been undertaken by any city in this country. Dr. Soper states that the present moment is propitious for such an investigation to be made as regards New York conditions, where the existing methods are yet crude and quite expensive, even though 40% of the work of collecting and disposing of the garbage is done by private parties, over which the city has but little control.

The writer suggests that in his opinion a further profitable investigation would be a full and detailed report on the entire subject, containing itemized expenses, and setting forth clearly the methods of operation and the results obtained in those cities of Europe where this subject has been settled satisfactorily, and, for comparison, an equally detailed report on the existing conditions in several of our own cities. Such a comparative report, the writer believes, would be of great value in pointing out specifically and most forcibly the courses to be pursued in solving this problem at home. In fact, unless we either present the public with actual information of this kind or make an actual impartial demonstration in one of our large cities, it would seem that the proper solution of the garbage question in this country will be still further postponed.

Mr. Ball makes an appeal for the disposal of street sweepings by burning instead of by filling in land, and offers many statements to support it. Such a disposition is made in several cities of Europe. In view of the fact that this material forms a rich field for disease germs, its incineration is certainly to be preferred when practicable. There are, however, many cases, particularly in our country, where the quota of combustible matter is reduced so greatly by admixture with mineral matter from badly paved or unpaved streets, that burning becomes expensive. In such cases filling in land is not only cheaper, but may be without sanitary danger. Mr. Ball further discusses the demolition of infected buildings, and gives the precautions which should be taken in their demolition. This subject had not before been touched upon, and is of sufficient importance to have been made a part of the subject under discussion. The writer believes Mr. Ball's precautions to be wise and practicable.

Commissioner Woodbury, by his remarks, leaves a doubt resting on the financial preference of the incineration over the reduction process, yet produces no facts to substantiate it. Mr. Parsons, on the other hand, unhesitatingly states his belief that incineration of the garbage of New York City is cheaper than its reduction, but, likewise, without substantiation. These, and other statements, confirm the opinion expressed by the writer, that experiments on a large scale, combined with an exhaustive inquiry into the subject, are required to demonstrate the best as well as the most economical disposal.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 946.

THE PANAMA CANAL.*

By George S. Morison, Past-President, Am. Soc. C. E.

With Discussion by Messrs. M. Meigs, Theodore Paschke, C. L. Harrison, W. E. Crane, Boyd Ehle, William H. Burr, P. Bunau-Varilla, L. J. Le Conte and George S. Morison.

On March 5th, 1902, a paper† on one of the most important features of the Panama Canal was presented by the writer. That paper was confined to a single detail, although a very important one. The present paper covers a larger scope, and takes up the principal features of the canal.

The Isthmian Canal Commission, in its report, tried to place the two canals, Panama and Nicaragua, as nearly on the same basis as possible; eliminating from each scheme special advantages and economies which might be applicable on one, but could not be on the other. There were several points on which the writer differed from his colleagues, and, while these differences do not affect the general conclusion, his individual views have influenced the present paper.

Much has been said of the great value of a tide-level canal and its unlimited capacity. This unlimited capacity is more apparent than real. A tide-level canal will require a tide lock at the Pacific end, and, although both gates can be left open at mean tide, so that the length

* Presented at the meeting of February 18th, 1903.

† "The Bohio Dam," *Transactions*, Am. Soc. C. E., Vol. XLVIII, p. 235.

of lock is not a limiting factor, its breadth and depth are. The difficulties of controlling floods are greater in the tide-level canal than in the canal with locks, and the advantage of a broad inland lake is lost. Still, the writer believes that the tide-level canal would be the better canal when done, but that the difficulties which would attend its construction, the greater cost, and especially the longer time involved, preclude its selection. In this paper both plans of canal are described, and comparative estimates given in some detail.

The locks are of enormous dimensions, and, while few engineers would doubt the feasibility of locks 800 ft. long, more than 80 ft. wide, with more than 40 ft. lift, conservatism cautions us against this great lift if it can be avoided. Partly for this reason, the writer has selected the Tiger Hill Cut-Off line for the high-level canal, which permits the rise from the Atlantic to Lake Bohio to be divided into three lifts instead of two, shortens the line, and places it farther from the Chagres. The old location is not condemned, but the cut-off is preferred. The fact that by the use of an intermediate level the head of water against the dam is reduced explains the difference in the seepage figures used in this paper and those calculated in the paper on "The Bohio Dam."

General Description.

At Panama the actual width of the Isthmus from tide water to tide water, in a straight line, is only 35 miles. The continental divide is about 8 miles from the Pacific, and in places less than 300 ft. above mean tide. Between this low mountain ridge and the Atlantic lies a hilly country, intersected by streams, the drainage of which is into the Atlantic through the Chagres River. The Chagres rises in the mountains about 60 miles east of the canal location and enters the Caribbean Sea some miles west of the Atlantic terminus of the canal. The valley of the Chagres, with the low country adjacent to it, forms a natural approach from the Atlantic side. To pass from this valley to the Pacific, it is necessary to go boldly across the low ridge of the Cordilleras. The route selected by the original French company for the Panama Canal is, in a general way, the same as that on which the Panama Railroad was built 30 years before. Subject to variations of detail, the routes are practically one, and the only possible route in this part of the Isthmus. The total distance by either rail-

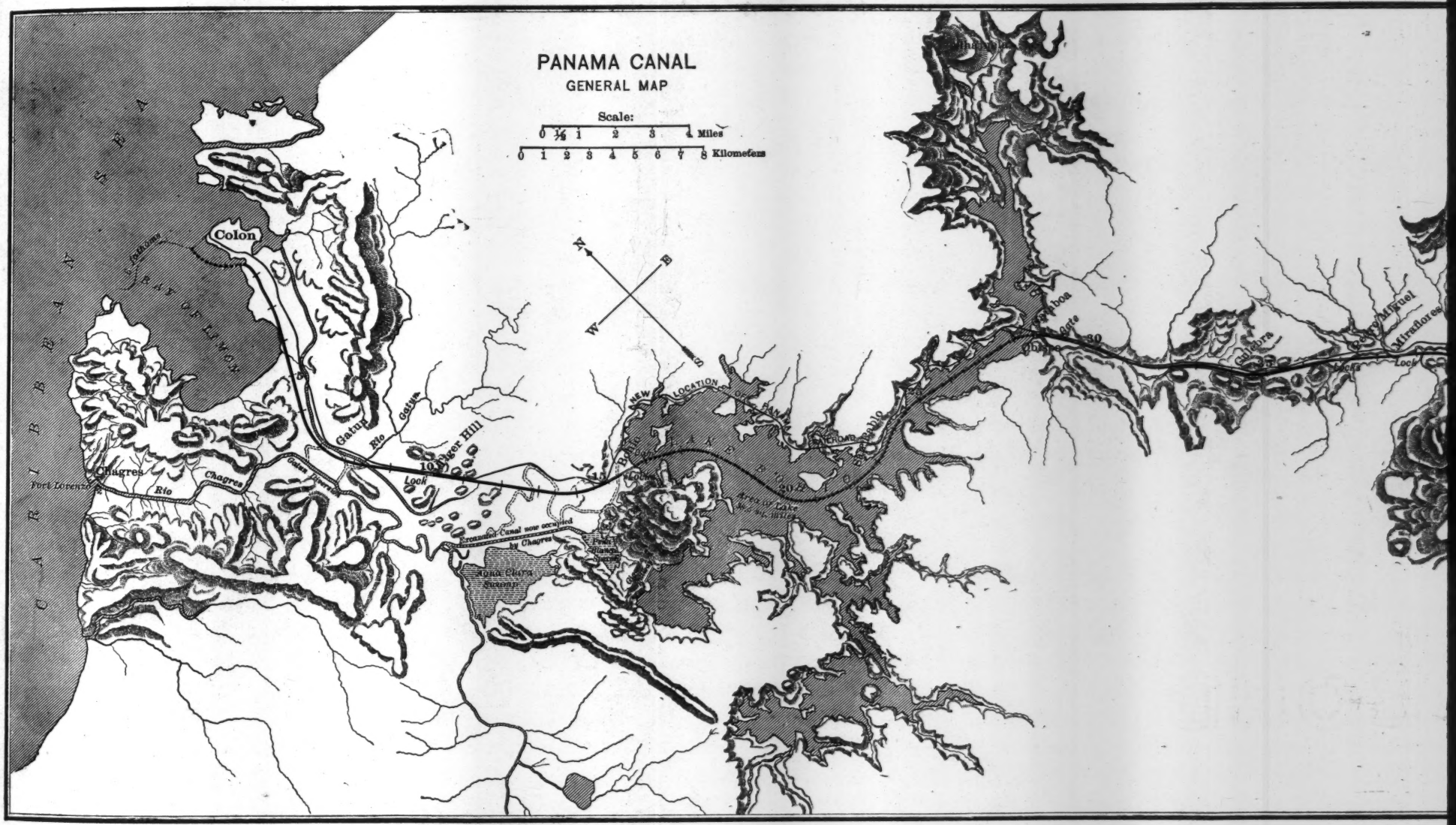
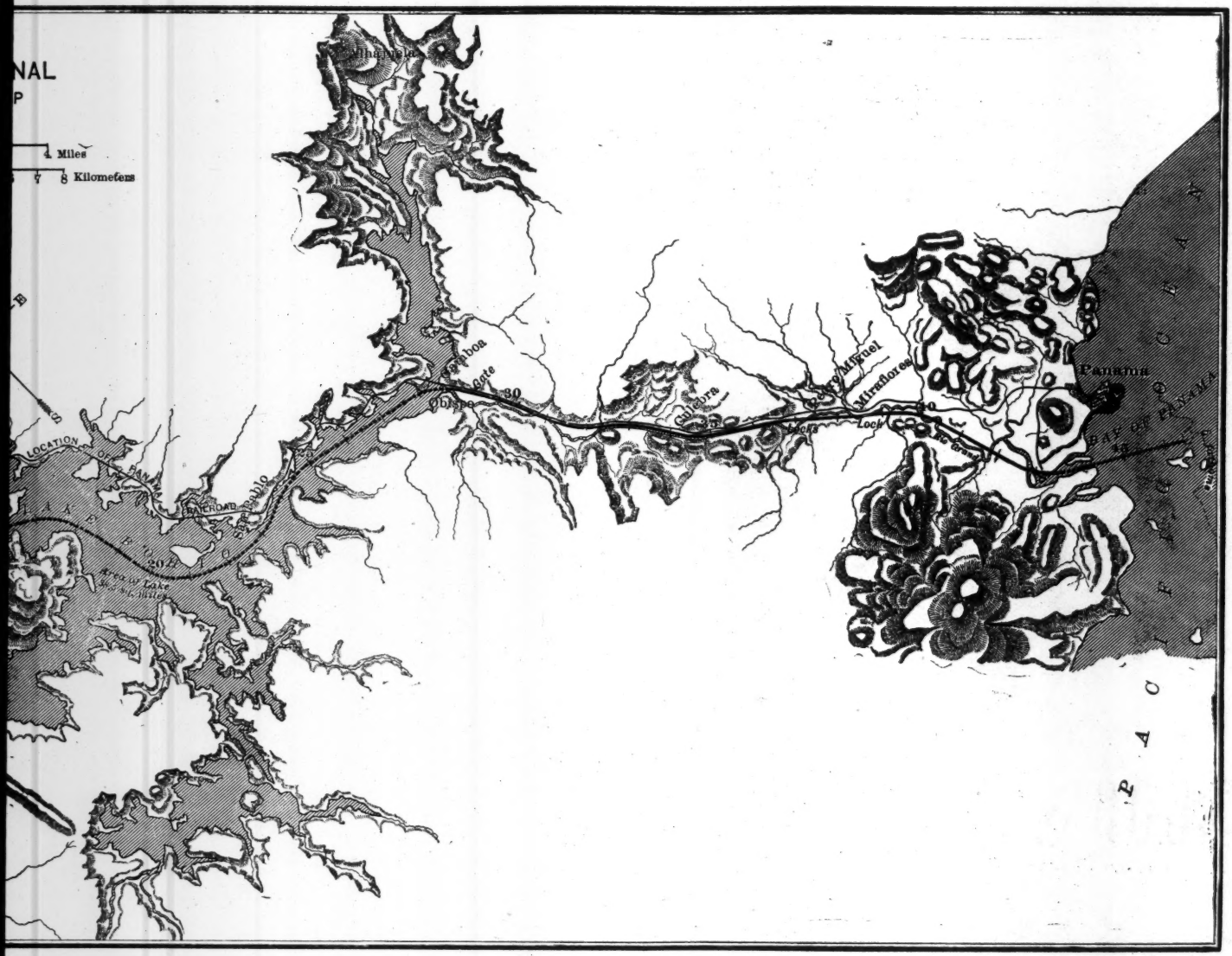

PANAMA CANAL
GENERAL MAP
Scale:
0 ½ 1 2 3 4 Miles
0 1 2 3 4 5 6 7 8 Kilometers
N
E
W
S
CARIBBEAN SEA
Colon
Chagres
Fort Lorenzo
Rio Chagres
Gatun
Rio Gatun
Lock
Tiger Hill
Excavated Canal now occupied by Chagres
Agua Clara Swamp
NEW LOCATION OF PANAMA
Bohio
Lake Bohio
Area of Lake
Gatun
Culebra
Miraflores
Lock

PLATE XIII.
TRANS. AM. SOC. CIV. ENGRS
VOL. L, No. 946.
MORISON ON PANAMA CANAL.



road or canal from deep water to deep water is, in round numbers, 45 miles, of which 27 miles are in the Atlantic coastal plain and the valley of the Chagres; 12 miles are in the passage of the ridge, and the balance in the low lands near the Pacific. Of the actual distance from the Atlantic shore line to the Pacific shore line, not including the extensions into deep water, almost exactly two-thirds, being the portion north of Obispo, are within the drainage of the Chagres, and one-third in the crossing from the Chagres to the Pacific.

The Chagres is a tropical mountain stream, with the excessive variations which belong to such a river. Its maximum flood discharge is approximately 200 times its minimum dry-season discharge. The area of its total drainage basin, though not completely surveyed, is about 1 200 sq. miles. It has a comparatively rapid fall, which is greatest near the source. At the point where the canal leaves the Chagres Valley to cross the divide, the bottom of the Chagres River is about 40 ft. above mean tide. The principal difficulties of the northern portion of the canal, from Colon to Obispo, lie in the control of the Chagres River; the principal difficulty on the remainder is the summit cut. In a tide-level canal, such as the original French Company proposed to build, these two difficulties were virtually all. With the abandonment of the tide-level scheme and the adoption of a summit level reached by locks, the problem of water supply for this summit level was added, but, as the only source of gravity supply for such summit level is the Chagres River, the problems of the control of this river and of the use of its water to feed the canal are very intimately connected.

Besides these, there are the harbors, which present difficulties, though not serious ones, at each end of the canal; the dimensions of locks which should be used, and the changes which the construction of the canal must necessarily make in the Panama Railroad. These matters call for only brief consideration.

The dimensions of the canal itself are of the utmost importance, and no estimates can be made, even of a preliminary character, without determining them. The dimensions adopted by the French Company are in a general way those of the Suez Canal. The Suez Canal is a salt-water canal throughout. The Panama Canal will be a fresh-water canal, and it will also be a warm-water canal, the water weighing 62.2 lbs. per foot, or about 3% less than the water of the ocean. The Suez

Canal has a depth of 9 m., or 29.5 ft. To accommodate ships of equal size, the Panama Canal should be at least 8 ins. deeper. The Suez Canal cannot accommodate the largest class of ships; the regulations of that canal limit the draft of ships passing through it to 7.8 m. or 25 ft. 7 ins., though ships of greater draft are sometimes taken through with the assistance of tugs. The largest steamers now plying between England and Australian ports cannot and do not pass through the Suez Canal. There is a large number of ships now in service on the Atlantic, the authorized draft of which is 32 ft. or more; one of these ships would draw 33 ft. in the Panama canal. The traffic which would pass through the Panama Canal would be of a character materially different from that which uses the Suez Canal; it would consist largely of heavy, coarse freight. As the size of a ship is, in a measure, a function of the length of voyage, it is probable that the largest class of freight carriers will use this canal. The Isthmian Canal Commission considered that the canal should have a depth of 35 ft., through which steamers drawing 32 ft. in salt water could pass without trouble, and the writer concurs in this decision.

In determining the width of the canal there is more room for difference of opinion. While depth may be considered a necessity, width is very largely a convenience. A ship can be taken through a canal with little clearance on either side, but it must be done very slowly; a much greater width will be required if any considerable speed is to be maintained, and still more if large ships are to pass each other in all portions of the canal. The dimensions adopted by the original French Company provided for a bottom width of only 22 m., or 72 ft.; the new French Company adopted a bottom width of 30 m., slightly increased in rock sections, or a little less than 100 ft. The Isthmian Canal Commission selected a bottom width of 150 ft., which was somewhat enlarged on curves. The increased width on curves in so large a canal is perhaps an over-refinement, but, in view of the experience of other great works, it is probably not wise to reduce the dimensions selected by the Commission.

Colon Harbor is virtually tideless, while Panama Bay has a tidal range of over 20 ft. The plans of the original French Company contemplated a depth of 9 m. below mean water at both termini, which would have made a channel of about 20 ft. at low water in Panama Bay. The plans of the new French Company proposed a depth of 9 m. below

low water in Panama Bay; the Isthmian Canal Commission's estimates are based on a depth of 35 ft. below mean low water in Panama Bay. A depth of 35 ft. below mean tide in Panama Bay would give 25 ft. in the canal under all conditions, 45 ft. at high water and 35 ft. for about 18 hours out of 24. In the opinion of the writer, this depth is quite as much as the demands of traffic are likely to justify.

With this preliminary statement, the main features of the canal may be described.

Control of the Chagres.

The discharge of the Chagres has been made a matter of special observation by the new French Company, and these observations have been verified and amplified by Arthur P. Davis, M. Am. Soc. C. E., for the Isthmian Canal Commission. While the conclusions from such studies cannot be regarded as absolutely accurate, the general conditions, of which little was known twenty years ago, may now be considered established. The greatest flood in the Chagres, of which there is any record, occurred in 1879, prior to the beginning of work by the old French Company. The two floods of which there is the most accurate information are those of 1890 and 1893.

The area of the drainage basin of the Chagres above Bohio, the location selected by the French Company for a dam, is estimated at 875 sq. miles. This watershed may be divided for convenience into three parts: the portion above Alhajuela, the point selected by the French Company for the upper dam; the portion between Alhajuela and Gamboa, which is practically the point where the canal leaves the river; and the portion between Gamboa and Bohio. The area of the upper division is approximately 510 sq. miles, of the middle division 135 sq. miles, and of the lower division 230 sq. miles. The areas of the watersheds above these three points, will, therefore, be as follows:

	Square miles.	Percentages.
Alhajuela	510	58
Gamboa	645	74
Bohio	875	100

The data concerning the flood of 1879 are meager, and consist only of water marks from which the discharge has been calculated on various assumptions, while there is no accurate information by which the duration of the flood or the aggregate discharge can be even approxi-

mately determined. The conclusions, generally, are to the effect that it was in excess of 70 000 cu. ft. per second at Gamboa and 100 000 cu. ft. per second at Bohio. The general opinion has been that these figures are too high, but Mr. Davis thinks that there is a possibility that they are too low and that the flood may have been nearly 100 000 cu. ft. per second at Gamboa, and have exceeded 130 000 cu. ft. per second at Bohio. The flood of 1890 attained a maximum of 75 000 cu. ft. per second at Bohio, and that of 1893 fell below 50 000 cu ft. per second. All these floods were of very short duration, the average discharge of the Chagres being about 2 000 cu. ft. per second at Alhajuela, 2 500 cu. ft. at Gamboa, and 4 000 cu. ft. at Bohio. The time in which the discharge at Gamboa would exceed 35 000 cu. ft. per second, or that at Bohio 50 000 cu. ft. per second, would probably not be more than ten days in twenty years. A suspension of traffic during these few days would not seriously reduce the value of the canal.

If a flood of 35 000 cu. ft. per second coming from the upper Chagres at Gamboa and of 50 000 cu. ft. at Bohio could be so regulated that it would not produce a speed much exceeding 3 ft. per second in the navigable portions of the canal, the commercial requirements would be met. The canal, however, must be so designed that a maximum flood would do no permanent harm, and this means a probable discharge of 100 000 cu. ft. per second at Bohio, with the possibility that 140 000 cu. ft. per second should be provided for. A speed of 3.3 ft. (1 m.) per second could be allowed in the canal without disturbing navigation; a speed of 5 ft. per second could be allowed without permanent injury to the work.

With these conditions, a channel of 15 000 sq. ft. cross-section would carry off a flood of 50 000 cu. ft. per second without interfering with navigation, and of 75 000 cu. ft. per second without injury to the canal. If a tide-level canal is to be built, it must either be given these dimensions in the Chagres Valley or independent channels must be provided to carry off the discharge of the river. As the canal is in the lowest part of the valley, the construction of these channels would be a matter of serious difficulty, and the simplest solution would be to make a canal large enough to take the full discharge, which would have the further advantage of furnishing a very large canal, in which navigation, under ordinary conditions, would be especially easy; this would mean a canal with a bottom width of about 400 ft. An approximate

estimate shows that the total amount of excavation for such a canal between Colon and Obispo would be 150 000 000 cu. yds., about one-sixth of which is likely to be rock. This channel, however, has practically no factor of safety, and, if the flood of 1879 should be repeated, it might prove inadequate. By building the dam proposed by the French Company at Alhajuela the discharge above that point could be temporarily stored, and the discharge through the lower valley kept within the capacity of the proposed canal. It may be roughly estimated that the cost of this Chagres section of a tide-level canal would be about $90 000 000. While this treatment would be heroic, it is practicable, and would be satisfactory when done.

If, however, a dam could be built across the valley of the Chagres, the whole valley would be converted into a lake of such dimensions that the currents in this lake, even during the most violent floods, would not be objectionable. This is, perhaps, the greatest advantage to be gained by using locks and a summit level, it is certainly second only to the reduction in the volume of the Culebra Cut. The further down the valley this dam can be placed, the greater will be the length of valley converted into lake. The lowest point, however, which has been found in any way suitable for a dam site is at Bohio, midway between Obispo and the terminus of the canal at Colon. A site for a dam in this neighborhood has been selected by the new French Company, and the Isthmian Canal Commission concurred in the expediency of building a dam in the same vicinity. By the construction of such a dam the valley is converted into a lake between Obispo and Bohio, and this lake would extend up the upper valley of the Chagres to a distance determined by the height of the dam. The Gigante, a lateral stream coming from the west, enters the Chagres about 4 miles above Bohio, and near the head of this stream is a low summit admirably adapted for a spillway. The limits within which the range of the lake could be confined would be determined by the length of this spillway. The Isthmian Canal Commission has proposed a spillway 2 000 ft. long. Using the formula

$$Q = 3.5\, h^{\frac{3}{2}}\, l,$$

we have the following results, if l is made 2 000:

$Q =$ 50 000	$h = 3.71$
75 000	4.86
100 000	5.89

It would appear, therefore, that heights of, respectively, 4, 5, and 6 ft. over the crest of the spillway would pass something more than 50 000, 75 000 and 100 000 cu. ft. per second for an indefinite period. The maximum floods, however, are of short duration, and a considerable amount would be stored in the lake, as its level is raised from the normal level to the extreme height of such a flood. With the surface of the lake at Elevation 85, corresponding to a bottom level at Elevation 50, as used in estimating the Culebra Cut, the surface area of this lake is 38.5 sq. miles, or about 1 075 000 000 sq. ft. A rise from a depth of 1 ft. to a depth of 5 ft. over the spillway would represent a storage of 4 300 000 000 cu. ft., an average of 50 000 cu. ft. per second for 24 hours, or 25 000 cu. ft. per second for two days. A detailed study shows that, with a discharge of 100 000 cu. ft. per second into the whole basin, the discharge is never likely to exceed 75 000 cu. ft. per second over the spillway, and 5 ft. may be accepted as the variation in the level of the lake. Should a greater flood occur it would merely mean a little higher level in the lake, which might possibly rise to about 6 ft. above the crest of the spillway. Furthermore, the canal through the Culebra Cut would have a cross-section, during this high water, of over 6 000 sq. ft., capable of taking off, at 5 ft. per second, a discharge of 30 000 cu. ft. per second; and the canal north of the Bohio Dam would have a cross-section of not less than 7 000 sq. ft., capable of taking off, at a speed of 3 ft. per second, 21 000 cu. ft. per second.

This general arrangement means a lake the surface of which varies from Elevation 85, when level with the top of the spillway, to Elevation 90, under extreme flood conditions, with a bare possibility of reaching Elevation 91. It involves a spillway at Gigante and a dam at Bohio, of which structures more will be said hereafter. Comparatively little excavation would be required in any portion of the lake, the total between the Bohio Dam and Obispo being barely 2 000 000 cu. yds,, of which, perhaps, one-fourth is rock, and the total cost of which would not exceed $1 000 000.

Below the Bohio Dam the old French location followed the valley of the Chagres about 9 miles to Gatun, where the Chagres turns abruptly to the west and enters the Caribbean Sea some miles west of Colon. This is, perhaps, the only location for a tide-level canal. For 4 miles of this distance the Chagres has absolutely abandoned its old course and flows through the canal. The discharge over the Gigante

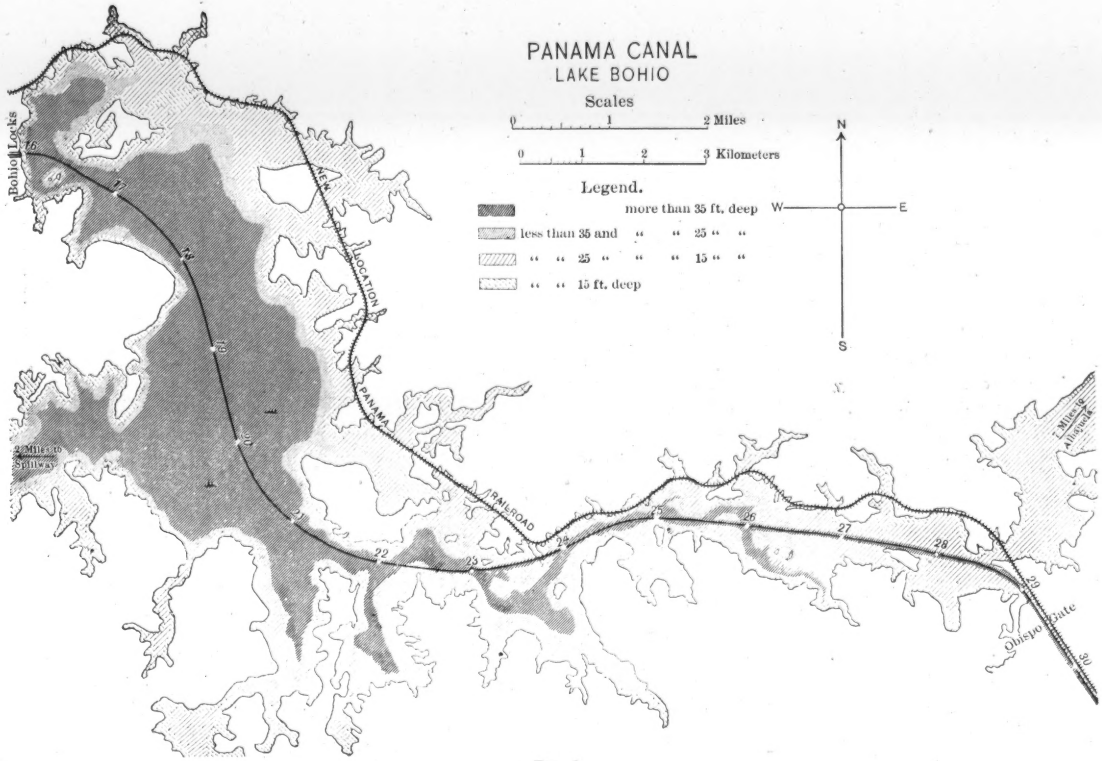

PANAMA CANAL
LAKE BOHIO
Scales
0 1 2 Miles
0 1 2 3 Kilometers
Legend.
more than 35 ft. deep
less than 35 and " " 25 " "
" " 25 " " " 15 " "
" " 15 ft. deep
N
W
E
S
Bohio Locks
NEW LOCATION
PANAMA RAILROAD
2 Miles to Spillway
2 Miles to Alhajuela
Obispo Gate
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

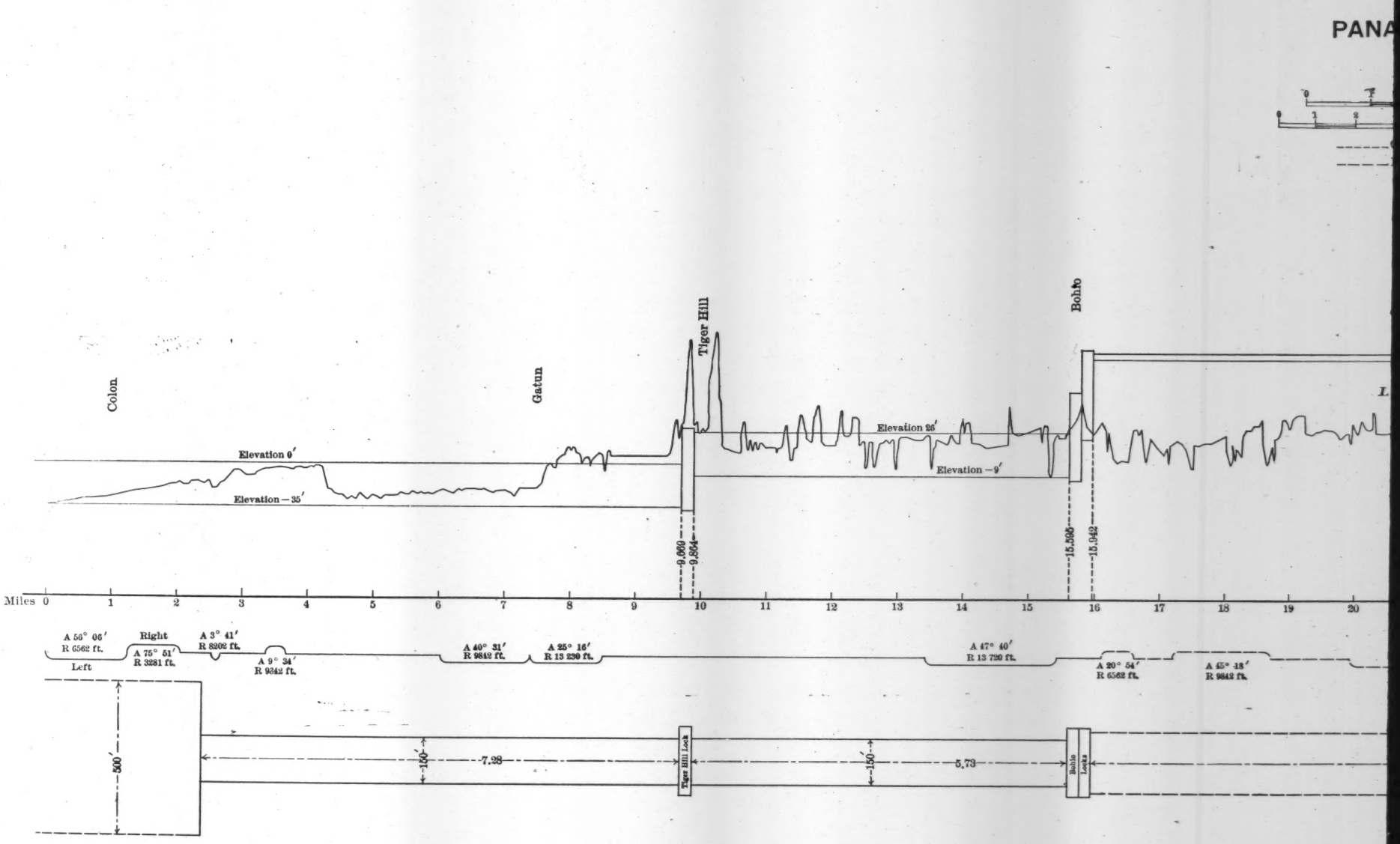
FIG. 1.

Spillway will enter the Chagres about 2 miles below Bohio; below this point one of three courses is practicable. The same course may be adopted that is proposed for a tide-level canal, giving the canal a section of such dimensions that it could pass the flood discharge within its own limits. The valley here is generally comparatively broad, and the floods can be kept out of the canal by constructing a levee on the west side of it; this plan involves a discharge channel between the two swamps, Peña Blanca and Agua Clara, besides which a new channel for the Chagres must be dug across a neck of land opposite Gatun and about three-quarters of a mile from the canal. A location can be adopted east of the Chagres Valley, between Bohio and Gatun, by which the canal can be kept a safe distance from the Chagres and for half the way at a safe height above it. This third plan has the advantage of saving 1¼ miles of distance. Furthermore, there is an excellent site for a lock at Tiger Hill, 6 miles from Bohio, by which it is possible to reduce the lift of the Bohio locks. This last line is preferred by the writer, and is used in this description. It is the line shown on the general map, Plate XIII. The level of the surface of the canal is maintained at 26 ft. above mean tide south of the Tiger Hill lock, the bottom of the canal being 9 ft. below mean tide. The one defect of this plan is that the water is carried a few feet above the level of the surrounding country, but there is such an enormous excess of excavation in the canal that an embankment of almost indefinite width can be built on the river side. This line joins the French location at Gatun, and the new channel for the Chagres opposite Gatun is still necessary.

The problem of the control of the Chagres is absolutely solved by the construction of three works: the Bohio Dam, the Gigante Spillway and the Gatun Diversion.

Water Supply.

The only source from which a supply of water for the summit level can be obtained by gravity is the Chagres River. The French plan, which contemplated a summit level above that of the lake, proposed to build a dam at Alhajuela and convey the water by a feeder, of complicated design, from the dam to the summit. The same arrangement was proposed by Captain E. P. Lull, U. S. N., in 1875. If the lake itself be made the summit level, any such feeder becomes unnecessary, and the canal will be fed at all times by the Chagres River and the


PANA
Colon
Gatun
Tiger Hill
Bohio
Elevation 0′
Elevation −35′
Elevation 26′
Elevation −9′
0.000
9.864
15.506
15.942
Miles 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
A 56° 06′
R 6562 ft.
Left
Right
A 75° 51′
R 3281 ft.
A 3° 41′
R 8202 ft.
A 9° 34′
R 9842 ft.
A 40° 31′
R 9842 ft.
A 25° 16′
R 13 230 ft.
A 47° 40′
R 13 780 ft.
A 20° 54′
R 6562 ft.
A 45° 13′
R 9842 ft.
500′
150′
7.28
Tiger Hill Locks
150′
5.73
Bohio Locks

PANAMA CANAL

PROFILE

Scales

0 1 2 3 4 Miles

0 1 2 3 4 5 6 7 8 Kilometers

------ Original ground surface

– – – – Drowned channel

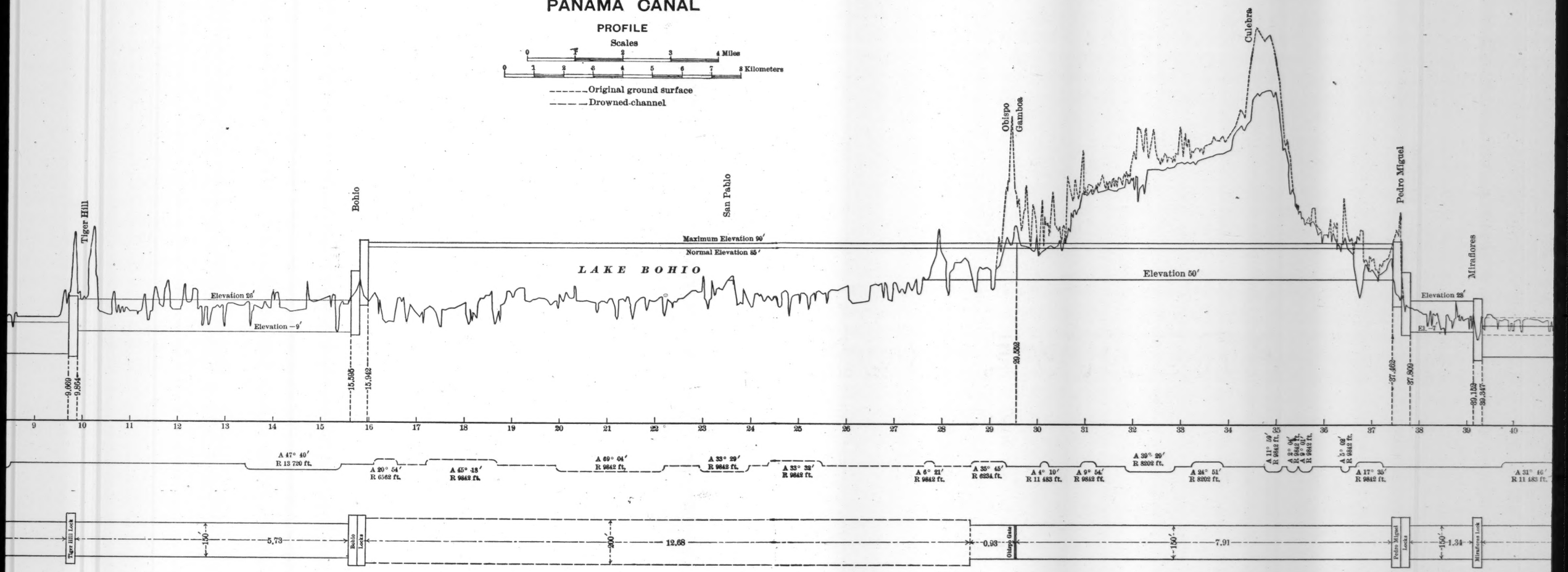


PLATE XIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. L, No. 946.
MORISON ON PANAMA CANAL.

PANAMA CANAL

PROFILE

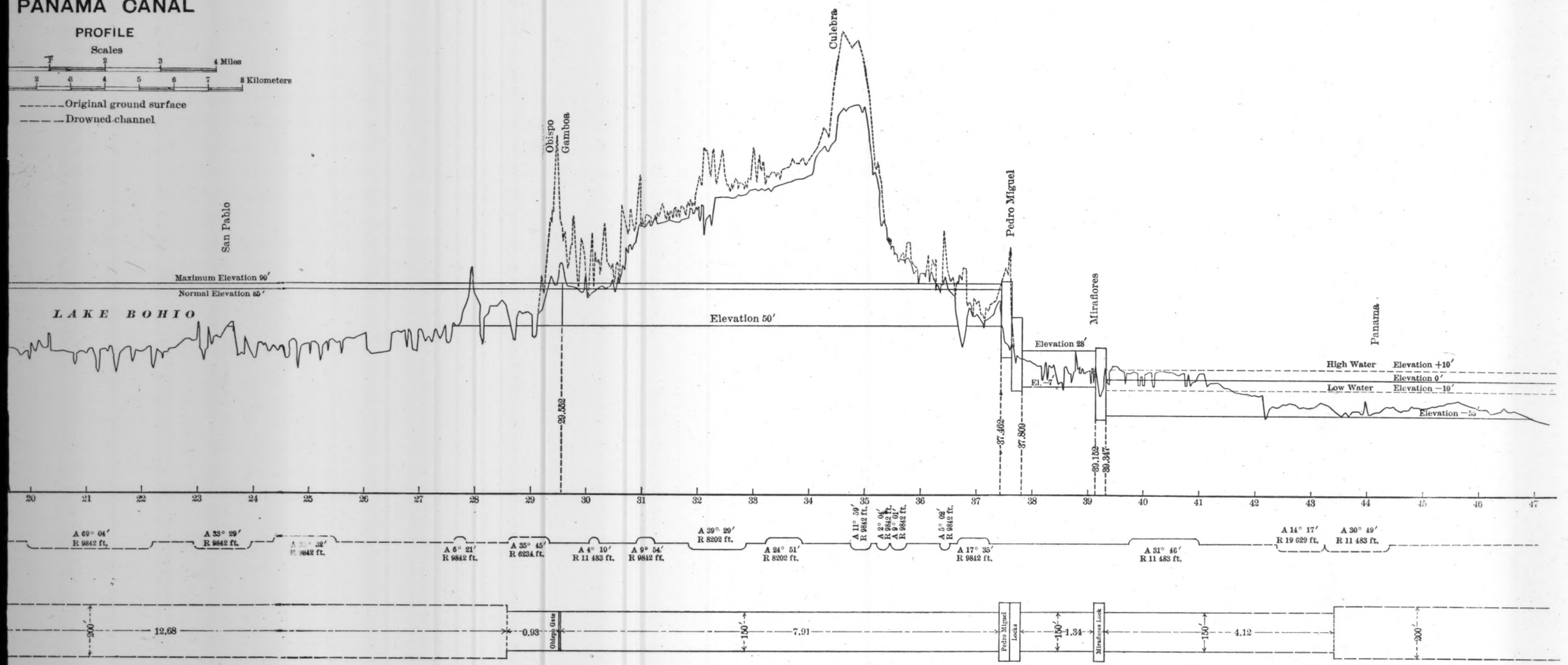
Scales

1 2 3 4 Miles

2 3 4 5 6 7 8 Kilometers

------ Original ground surface

– – – – Drowned channel



various tributaries which are intercepted by the lake. Were the discharge of the Chagres and its various affluents at all times equal to the demands of the canal, no further provision would be required. There is, however, a short period in the early part of each year when the supply is always small and sometimes inadequate. The actual demands for water for canal uses may be limited to three purposes: lockage, seepage and evaporation. Besides this, the French estimates have made provision for power, but this is hardly an actual necessity of the canal, and can be provided in other ways, if the water supply is inadequate. Furthermore, the amount of water actually needed for power is, in the aggregate, exceedingly small.

With the water in the lake at a normal elevation of 85 there will be a descent of 59 ft. to the intermediate level on the Atlantic side, and of 59 ft. to the intermediate level on the Pacific side, an average of 58 ft. Each descent is accomplished by two locks, the average lift of which, in the period when an economy of water is important, is 29 ft. These locks, according to the plan adopted by the Isthmian Canal Commission, are 84 ft. wide and 790 ft. long between gates; each lock chamber contains, therefore, 1 924 470 cu. ft. If it be assumed that ten vessels pass through the canal daily, each using two full locks of water, one ascending and one descending, the total daily consumption will be 38 488 800 cu. ft., or 445 cu. ft. per second. This amount will be reduced materially if intermediate gates are provided in the locks so that smaller vessels can take less than a lockfull of water.

The seepage will be confined principally to the Bohio Dam. There is a short piece of embankment near the Gigante Spillway, but it is of such insignificant dimensions as to be of no importance. Elsewhere, the summit lake is confined between the natural walls of mountain valleys. Estimated on the basis used in the paper on "The Bohio Dam," but with the head reduced to 60 ft., the requirement for seepage would be 28 cu. ft. per second.

To the seepage proper must be added the waste of water at the locks. This will depend very largely on gate construction, character of valves, and care of lock tenders. A provision of 200 cu. ft. per second would seem to be ample.

The area of the lake is 38.5 sq. miles, or 1 075 000 000 sq. ft., and the evaporation over this area, taken at 0.5 ft. per month, or 0.0167 ft. per day, or 0.00000019 ft. per second, amounts to 207 cu. ft. per second over the whole area of the lake.

This makes the entire water requirement, with no provision for power, 880 cu. ft. per second. These figures will vary on different assumptions, but it is safe to say that 1 000 cu. ft. per second would be a generous supply for any traffic that is yet in sight. Furthermore, with the tendency to increase the size of ships, it is probable that the actual number of ships will be less, rather than more, than ten daily.

In a general way, it may be said that, out of a total of 1 000 cu. ft. per second, 450 cu. ft. will be required for lockage, 250 cu. ft. for seepage and leakage at gates, and 200 cu. ft. for evaporation, leaving 100 cu. ft. per second for margin and power. This quantity of water, 100 cu. ft. per second, falling 85 ft., will produce about 800 H.-P. on the shaft of a turbine wheel.

The average monthly discharge of the Chagres at Bohio always exceeds 1 000 cu. ft. per second, except during a period of varying length in the months of February, March, April and May. It may have fallen as low as 350 cu. ft. per second for a few days. The French Company has kept daily observations at Bohio of the stage of water for about ten years. From these stages the daily rates of discharge have been calculated, and from these results it is easy to determine the deficiencies, below an average of 1 000 cu. ft. per second, which have occurred during the period of these observations. These deficiencies for nine years are shown in Table No. 1, the last column of which shows the depth of water in the lake corresponding thereto.

TABLE No. 1.

Year.	Cubic feet.	Feet.
1891	2 600 000 000	2.42
1892	291 600 000	0.27
1893	1 166 400 000	1.09
1894	637 000 000	0.60
1895	864 000 000	0.80
1896	648 000 000	0.61
1897	1 728 000 000	1.61
1898	Records incomplete.	
1899	172 800 000	0.16
1900	1 296 000 000	1.21
1901	230 000 000	0.21
1902	0	0.

There are several ways to provide for this deficiency. The first would be to take it from the lake, which has an area of 1 075 000 000 sq. ft.; the last column of Table No. 1 shows that this reduction would still leave it possible for ships drawing 30 ft. at sea to pass through. Another method would be to lower the bottom of the canal through the summit level 3 ft.; this is the plan proposed by the Isthmian Canal Commission; it would add about 1 500 000 cu. yds. to the Culebra Cut, besides increasing the height of the long retaining walls and the cost of the locks; it may be roughly estimated as adding from $2 500 000 to $3 000 000 to the cost of the canal. Another method would be by the construction of the Alhajuela Dam, proposed by the French Company, by which a lake could be formed in the upper Chagres Valley, in which 15 000 000 000 cu. ft. of water could be stored. If the construction of this dam were deferred until after the completion of the other work, so that the lake could be used for transporting material, Elevation 85 carrying still water almost to the site of the dam, the cost of the dam would not exceed the cost of deepening the lake, and it would have the further advantage of storing water above the dam, by which the violence of the floods below the dam would be diminished. A fourth method would be by the use of the old Yankee device of flash-boards, by which the level of the lake could easily be raised 3 ft. above the crest of the spillway, without involving any increase in the height of water during extreme floods. In the judgment of the writer, the canal should be opened with no special provision for additional water supply during the dry months, other than what would be obtained by lowering the level of the lake or by the use of flash-boards. Experience will show what additional storage is required, and, if needed, it can be more economically provided after the other works are completed than before.

Ten lockages each way daily represent the passage of 3 650 ships a year, if no two ships are ever passed together through the same lock at the same time. This would undoubtedly be done occasionally with small vessels. If 10% is added on this account, they represent a passage of 4 000 ships a year, and if these have an average of 2 500 tons, net, they represent a total of 10 000 000 tons yearly. The number of ships passed through the Suez Canal in 1901 was 3 699, the average net tonnage being 2 926 tons. It is probable that the average net tonnage will be at least 4 000 tons when the Panama Canal is opened, and that ten lockages each way daily would represent at least 15 000 000 tons.

It is important, however, to consider the possibilities of water supply for larger traffic. Of the 1 000 cu. ft. per second required for the wants of the canal, 450 cu. ft. are consumed in lockage. If, therefore, the number of lockages is doubled, representing a passage of at least twenty ships daily, the requirements are 1 450 cu. ft. per second; thirty passages would require 1 900 cu. ft. per second, and forty passages 2 350 cu. ft. per second. The length of time when the discharge of the Chagres falls below these requirements increases with the amounts, but in no instance of which we have any record has it fallen below the maximum requirement of 2 350 cu. ft. per second for a continuous period of more than four months. The deficiencies below these requirements are given in Table No. 2, and are shown in the diagram, Fig. 2.

TABLE No. 2.

Year.	Below 1 450 cu. ft.	Below 1 900 cu. ft.	Below 2 350 cu. ft.
1891	5 437 000 000	9 435 000 000	13 712 000 000
1892	1 069 200 000	2 575 600 000	6 505 900 000
1893	2 760 500 000	5 376 500 000	8 456 700 000
1894	3 164 200 000	6 531 600 000	11 095 700 000
1895	2 140 600 000	5 056 600 000	8 084 900 000
1896	2 708 600 000	5 585 700 000	8 873 900 000
1897	4 060 800 000	7 171 200 000	10 476 000 000
1898	1 555 000 000	3 382 000 000	6 363 000 000
1899	2 702 400 000	5 546 300 000	9 977 900 000
1900	4 523 000 000	8 217 000 000	12 494 000 000
1901	4 900 840 000	8 985 140 000	13 261 940 000
1902	505 400 000	2 605 000 000	5 326 600 000

To meet this deficiency it will be necessary to build a dam at or near Alhajuela. A dam built there, of the height proposed by the French engineers, would form a lake with a total storage capacity of 14 700 000 000 cu. ft. The greatest deficiency (13 712 000 000 cu. ft.) would require a storage of 660 cu. ft. per second for a period of eight months, making the total average requirements for these eight months 3010 cu. ft. per second. The least discharge for eight months, of which there is any record, occurred in 1899 and averaged 4 340 cu. ft. per second, showing that there is ample margin for evaporation and contingencies.

The last supposition provides for 14 600 passages yearly. Before this number of ships is reached it is probable that the average tonnage

PANAMA CANAL

DEFICIENCIES IN WATER SUPPLY

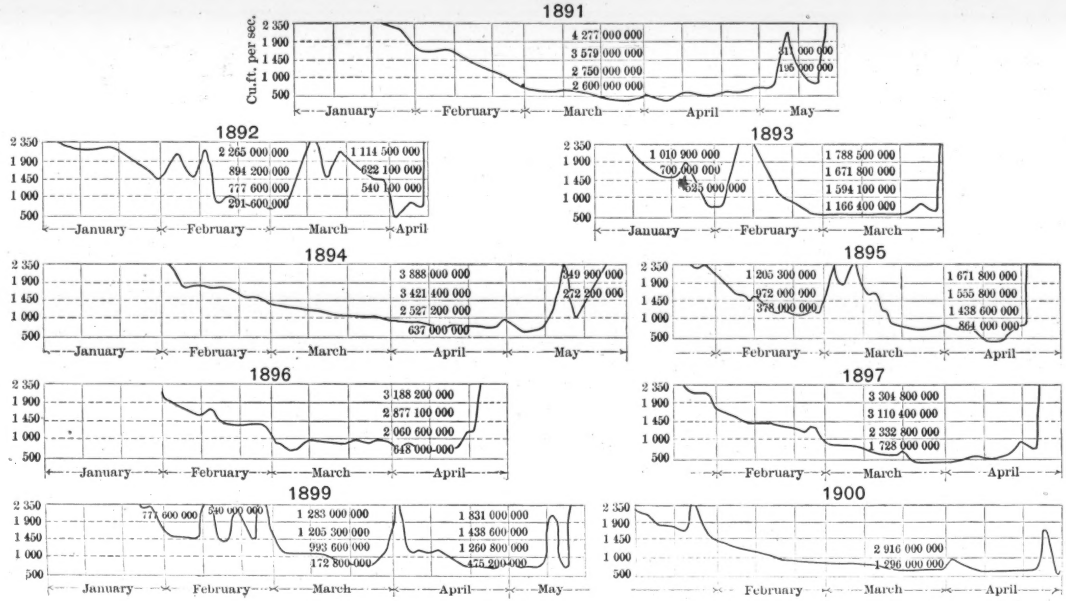


FIG. 2.

will be more than doubled and that this will represent a traffic of from 80 000 000 to 100 000 000 tons annually.

The system now proposed for the control of the Chagres and for the supply of water to the summit level is entirely automatic, except under two conditions which would very rarely occur. In case of extreme flood, if it is desired to pass any water through the canal, it must be done by opening the lock valves or the gates of a special by-pass. If the Alhajuela Dam is built to make an upper storage reservoir, gates must be opened by which the water will be received from that reservoir; or, if flash-boards are used, those flash-boards must be replaced after floods of exceptional violence, an operation of the very simplest kind. The beauty of the plan recommended is that, in boldly treating the subject as a whole, the annoyance and dangers of detail are avoided.

Culebra Cut.

The term "Culebra Cut" is applied by the French Company to the single mile of cutting of greatest magnitude. As used in this paper it is understood to apply to the entire cut between the Chagres Valley and the point where tide water is first reached on the Pacific side, the northern terminus of this cut being at Obispo and the southern terminus at Pedro Miguel, a total distance of nearly 8 miles, of which the southern 2 miles are in a comparatively low country. For 5 miles this cut is really through a mountain, the maximum original height, on the center line of the canal, being 330 ft. above mean tide. While in the upper part of the work where the cut was first opened there is some soft and slippery clay, nearly the whole of this excavation must be made through a material which has generally been rated as rock. It is, in fact, an indurated clay, not firm enough to class as shale, but perhaps quite as hard to work. It is intersected here and there by thin strata and dikes of hard limestone. It is a material which would weather rapidly and go to pieces in a northern climate where there is frost; in the damp warm climate of the Isthmus it does better, but when fragments are immersed in water they fall into powder, and it would evidently be unsafe to expose the unprotected sides of this excavation to the wash of the water in the canal. It was the judgment of the Commission, in which the writer fully concurs, that this cut should be estimated on the basis of slopes of 1 on 1,

which is a little flatter than the slope adopted by the new French Company. This does not mean that the cut would be excavated to those lines. The plan selected by the French Company, consisting of a number of benches connected by comparatively steep slopes, is probably the best way to finish the sides of the cutting, but it was thought that an estimate based on uniform slopes of 1 on 1 would give aggregate results quite as close to the actual work as could be obtained by more complicated calculations; furthermore, it would probably leave a margin to cover such special repairs as may be found necessary where faults and weaknesses appear on the slopes. On the basis of 150 ft. bottom width and slopes of 1 on 1, this cut, 7.95 miles long between Obispo and Pedro Miguel, with the bottom at an elevation of 47 ft. above mean tide, was estimated by the Isthmian Canal Commission to contain 43 237 000 cu. yds. With the depth remaining constant, each foot of increased or decreased width would represent, approximately, 150 000 cu. yds., provision being made for retaining the full width at a passing point, 1 600 ft. long, near the middle of this section. As the side slopes are 1 on 1, the bottom width being constant, each foot that the bottom is raised or lowered would represent an approximate decrease or increase of 300 000 cu. yds., besides the bottom excavation above or below Elevation 47. If the bottom were raised 3 ft., to Elevation 50, it would save 1 600 000 cu. yds., reducing the volume to approximately 41 600 000 cu. yds. If the width of this cut were reduced from 150 to 100 ft., this would represent a further approximate saving of 7 500 000 cu. yds.

On the other hand, if the bottom of the canal were lowered to 35 ft. below mean tide, the bottom width being reduced to 100 ft., reverting to the original de Lesseps scheme for a tide-level canal, the amount of excavation in crossing the divide would be increased to about 85 000 000 cu. yds. While this quantity is enormous, it is not beyond the capacity of a well-conducted work.

The concentration of so large an amount of excavation in so small a distance is without precedent. The engineer will recognize at once that it requires thorough organization, and tools specially adapted to the work. The large plant provided by the old French Company is now from fifteen to twenty years old. Those years have been years of unusual development in this class of machinery. Time is of the utmost importance. The wisest course would be to consign practi-

cally everything which is now on the Isthmus to the scrap heap, and handle this work with the best modern tools that can be obtained; some of these might be tools which could be bought in the market, but many must be specially designed for this particular work. Fortunately, there is ample ground on which to deposit the spoil from this great cut both north and south of the divide, but the manner of conducting the work, both in general principles and in detail, should be thoroughly worked out before actual execution is begun. No work has ever been undertaken on which the highest class of practical engineering talent could produce so great economies as in this particular great concentrated excavation. The Isthmian Canal Commission estimated the cost of this excavation at 80 cents per cubic yard; bad management would quickly raise this to a dollar, and it is not impossible that with a carefully considered equipment the cost could be reduced to 60 cents. In this single cut $25 000 000 is an easy measure of the difference between competent and incompetent management.

As already stated, it is thought unsafe to allow the earth in this cut to be washed by the water of the canal. The French plans have recognized this and have provided for facing the slopes of the canal with masonry. The construction of this cut interferes with the old line of the Panama Railroad. With the canal completed, the railroad will have little value except as a tender to the canal, and its most convenient location would be close to the canal. It is important to provide broad benches between the water of the canal and the slopes of the cut, so that any material which may break loose on the slopes can be stopped and handled before it reaches the water of the canal. It is desirable, if the sides of the canal are lined with masonry, to have this masonry nearly vertical, so that there would be no danger of a ship striking the masonry lining below water. These requirements are met by a special cross-section, which is shown in Fig. 3. The masonry walls may appear unnecessarily expensive, but their function is triple—they protect the slopes from the wash of the water; they accommodate the Panama Railroad; and they provide a bench in case of accident on the slopes. These walls should be provided for a length of 32 000 ft.—about 6 miles. They would contain in the aggregate 1 200 000 cu. yds. of concrete masonry, and their length and cost is practically independent of the elevation of the canal bottom or the width of the canal.

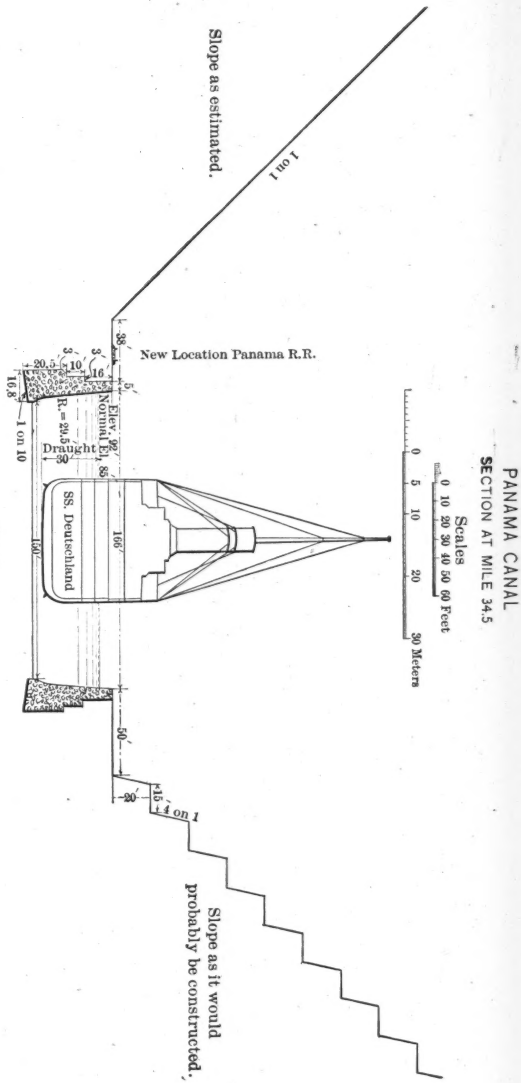

PANAMA CANAL
SECTION AT MILE 34.5
Scales
0 10 20 30 40 50 60 Feet
0 5 10 20 30 Meters
Slope as estimated.
1 on 1
New Location Panama R.R.
38'
3'
3'
20.5
10'
16'
5'
16.8'
1 on 10
R.=29.5'
Draught
30'
Elev. 92'
Normal El. 85'
SS. Deutschland
150'
166'
50'
20'
15'
4 on 1
Slope as it would probably be constructed.

FIG. 3.

Combining these two results and using the price of 80 cents per cubic yard for excavation and $8 per cubic yard for concrete masonry, we have as an approximate estimate of the cost of this cut, with a bottom width of 150 ft. at Elevation 50, $43 000 000. Each foot of increased width will represent an additional cost of $120 000, and each foot that the bottom may be lowered will represent an additional cost of about $400 000.

A tide-level canal 35 ft. deep, with a bottom width of 150 ft. between Obispo and Pedro Miguel, would cost nearly $90 000 000.

Intermediate Levels.

There would be two intermediate levels—a level 5.58 miles long between the Bohio and Tiger Hill locks on the Atlantic side, and a level 1.27 miles long between the Pedro Miguel and the Miraflores locks on the Pacific side.

The former may be designated as the Tiger Hill Level and the latter as the Miraflores Level.

The normal surface of the water in the Tiger Hill Level is at Elevation 26, the bottom of the excavation being at Elevation — 9. This level involves nearly 8 000 000 cu. yds. of excavation, of which about one-third would be rock. Its estimated cost is about $5 000 000. For a portion of the distance the water in the canal is carried above the level of the surrounding country, and it is carried across the bed of the Chagres three times, twice at places where that bed is already abandoned, and once at Bohio, where the river will continue to flow until the discharge of the lake through the Gigante Spillway is accomplished. No complete borings have yet been taken along this line of the canal, but the indications are that no serious trouble is to be expected, the only possibility being leakage, which can be controlled by a moderate amount of puddling.

The normal surface of the water in the Miraflores Level is at Elevation 28, the bottom of the excavation being at Elevation — 7. This level is perfectly straight, and involves only 1 200 000 cu. yds. of excavation, of which one-quarter may be rock. The estimated cost is $800 000. This section is really the deepening of a natural valley, and the surface width of the water will exceed that of the canal proper. A small fixed dam, which will act as a spillway, will be required adjoining the Miraflores Lock.

Maritime Levels.

The Atlantic Maritime Level will be 9.33 miles long, from the 6-fathom contour in Colon Harbor to the Tiger Hill lock, of which seven-tenths of a mile will be outside the terminus of the French Canal. The difficulties of the 35-ft. channel are more marked here than at any other place. Colon Harbor practically lies entirely within the 6-fathom contour, so that the channel has to be extended from the terminus proposed for the French Canal completely through the harbor to deep water. It is probable that a considerable amount of coral rock will be met in excavating this line to deep water, although the exact amount is not known. The cost of the channel outside the terminus of the French Canal, excavated with a bottom width of 500 ft., was estimated by the Isthmian Canal Commission at $1 284 270. This work could be deferred until after the opening of the canal, but it must be done before the largest class of vessels can be accommodated. Very careful and full surveys must be made of this portion of the bay before the best location for this deep-water channel can be determined, and it is possible that it may be found best to cut through the artificial point on which the statue of Christopher Columbus now stands, making the terminus of the canal near the northern end of Colon, at which point some kind of protective breakwater may then be required. The 8.92 miles of canal proper, from the terminus of the French work, opposite the statue of Columbus, to the Tiger Hill lock, would involve an excavation of 14 761 669 cu. yds., this including an allowance for an inshore basin, and is estimated to cost $9 813 000, making the approximate cost of the entire maritime section $11 100 000, of which $1 300 000 can be deferrred until after the opening of the canal.

The Pacific Maritime Section is 8.60 miles long from Miraflores lock to the 6-fathom contour in Panama Bay. Of this, 5.50 miles are canal proper, through a very low country, and the remaining 3.10 miles are open channel, through Panama Bay. This section involves the excavation of nearly 7 000 000 cu. yds., of which about one-fifth would be rock under water—the most expensive kind of excavation—and the remainder hydraulic dredging—the very cheapest kind of excavation. The estimated cost of this level is somewhat less than $8 000 000.

The description already given of the tide-level canal has included the line through to deep water in the Atlantic. On the Pacific side, the work between the Miraflores lock and the 6-fathom contour would be

identical with that of the high-level canal. The Miraflores lock would be required as a tide lock. The Miraflores Level would be lowered 28 ft. The excavation on this level would be, approximately, 2 500 000 cu. yds., at a cost of, approximately, $2 500 000, a portion being rock under water.

SPECIAL STRUCTURES.

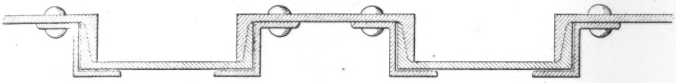
If the tide-level canal were adopted, but two special structures would be required—a tide lock at Miraflores and a dam at Alhajuela, the object of the dam being simply to check the flow of extreme floods, and its construction could be deferred until the completion of the canal. The lock at Miraflores would be fitted with double gates and used strictly as a tide lock. In cases of extreme floods the gates should be kept closed at all times, so as to prevent any undue current through the summit cut. Under ordinary conditions it might be expedient to leave all the gates open when the tide is above mean stage, thus allowing a moderate current to flow from the Pacific to the Atlantic during high tide. The exact working of such a lock would, however, be determined by experience. The approximate cost of the lock and the Alhajuela Dam, including a railroad to the dam site, may be taken at $8 000 000.

On the high-level canal there would be six important constructions, besides five other works of less size. These eleven constructions are as follows:

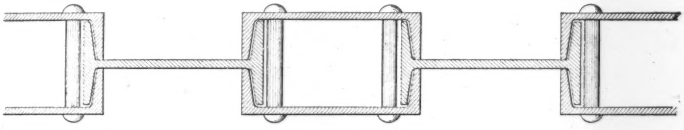
1.—Bohio Dam;
2.—Gigante Spillway;
3.—Bohio Locks;
4.—Pedro Miguel Locks;
5.—Tiger Hill Lock;
6.—Miraflores Lock;
7.—Obispo Gates;
8.—Tiger Hill Spillway;
9.—Miraflores Spillway;
10.—Diversion Channel near Gatun;
11.—Diversion of Panama Railroad.

Bohio Dam.—The summit level is sustained by the Bohio Dam, although its height is regulated by the Gigante Spillway. The situation of the dam, about 3 miles away from the spillway, is very important. The functions of the dam are confined to holding back the water, the dam never being exposed to any currents, either above or

below, and the only source of danger being wave action and possible infiltration. The plan of dam which the writer prefers is described in the paper on "The Bohio Dam."* Since that time his attention has been called to two forms of metallic sheet-piling, one designed by Mr. George W. Jackson, of Chicago, and the other one known as the Friestedt system, either of which seems to admit of penetration to very great depths, and may form an inexpensive and available method of absolutely closing the seepage through the valley, should such closure be considered sufficiently important. These arrangements of sheet-piling are shown in Fig. 4.



FRIESTEDT SYSTEM



JACKSON SYSTEM

FIG. 4.

Gigante Spillway.—The Gigante Spillway, although a work of considerable magnitude, involves no special difficulties in construction, as rock is found for its entire length above tide-water level. It would be built in the form of a masonry dam with a crest 2 000 ft. long. The estimated cost of this spillway is $1 200 000, this including the excavation for the foundation and such excavation as is necessary to make a clear approach for the water from the lake.

Locks.—There will be four sets of locks, of which two, at Tiger Hill and Miraflores, have a single lift; and two, and Bohio and Pedro Miguel, a double lift. It is proposed to build twin locks in every case, so that an accident to a single lock would not close the canal to traffic. The construction of the second lock would, however, be properly deferred until after the opening of the canal. This arrangement requires twelve lock chambers, in all.

Transactions, Am. Soc. C. E., Vol. XLVIII, p. 235.

The plan of the French engineers involved sixteen lock chambers, which they estimated to cost 137 000 000 francs, or 8 562 500 francs per chamber—in round numbers, $1 700 000 per lock chamber.

The Isthmian Canal Commission, estimating on the line now recommended, made the cost of the locks $29 189 994, an average of $2 432 500 per lock chamber.

It is probable that a considerable saving could be made by using metal in combination with the concrete of the locks, but, for present purposes, the estimate of the Isthmian Canal Commission may be accepted, and the cost of the locks given in round numbers as $29 000 000, of which about $17 000 000 would represent the cost of the first set of locks and $12 000 000 the cost of the second or twin locks.

Obispo Gates.—Conditions can be conceived of in which it will be important to draw off the water from the Culebra Cut without disturbing the water in the lake. For this purpose a pair of gates should be placed at the north end of the cut. These gates, if made 100 ft. wide, with the necessary masonry and excavation, are estimated to cost $300 000.

Tiger Hill and Miraflores Spillways.—Two spillways are required, one adjoining the Tiger Hill lock and the other adjoining the Miraflores lock, to take care of excess water in the intermediate levels. These are small affairs, the estimated cost of the two being less than $100 000.

Diversion Channels.—The principal diversion channel required will be that across the peninsula opposite Gatun; this would be a cut of considerable magnitude, and much of it would be through rock. It has been estimated of sufficient size to give a cross-section of 10 000 sq. ft. In addition to this the diversion channel dug along the east side of the canal by the old French Company must be put in order to take the discharge of the Gatun and the various other local streams which would otherwise enter the canal. An allowance of $2 000 000 should be made for these works, nearly all of which will be for the Chagres Diversion.

Diversion of Panama Railroad.—Both tide-level and high-level canals interfere with the Panama Railroad, the latter much more than the former.

For the canal described in this paper, the location of the Panama Railroad will have to be changed for a short distance near Tiger Hill

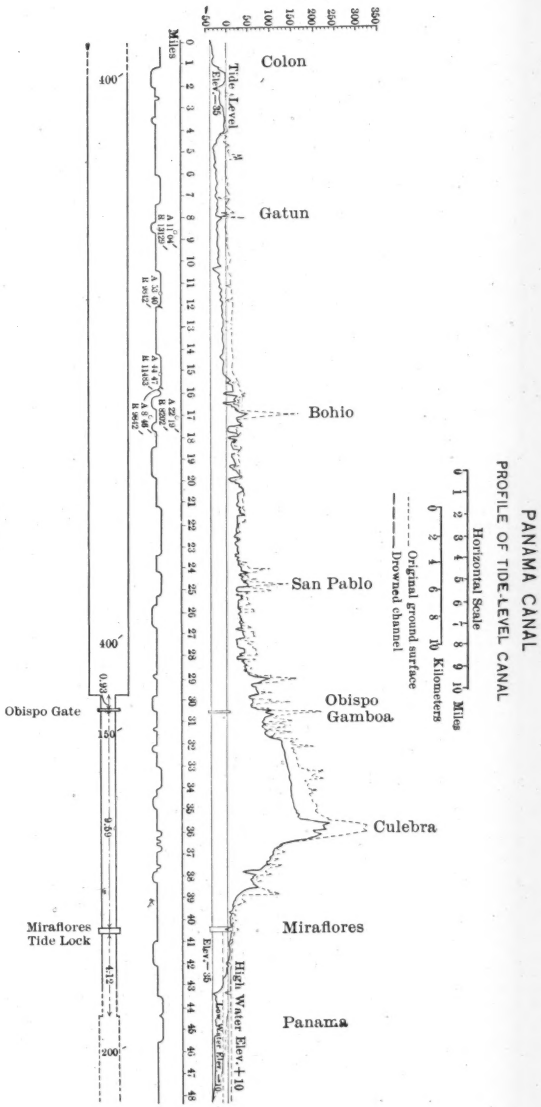

PANAMA CANAL
PROFILE OF TIDE-LEVEL CANAL
Horizontal Scale
0 1 2 3 4 5 6 7 8 9 10 Miles
0 2 4 6 8 10 Kilometers
Original ground surface
Drowned channel
Colon
Gatun
Bohio
San Pablo
Obispo Gamboa
Culebra
Miraflores
Panama
Tide Level
Elev.—35
High Water Elev.+10
Low Water Elev.—10
Miles
Obispo Gate
Miraflores Tide Lock
400′
150′
200′
0.93
9.59
4.12

FIG. 5.

and for the entire distance between Bohio and Obispo, while from Obispo to Pedro Miguel the railroad would be carried through the cut made for the canal. The cost of these changes in the Panama Railroad is estimated at $1 300 000.

The tide-level canal interferes but little with the Panama Railroad; but, in order to avoid crossing the canal, a new line of railroad should be constructed from San Pablo to Obispo, about 6 miles, and the railroad should be carried through the cut between Obispo and Pedro Miguel; these changes would probably not cost more than $500 000.

ESTIMATES.

The estimates made in this paper are based on the report of the Isthmian Canal Commission, modified to suit changes in plans. In general, round figures have been taken, as it seems unwise to confuse the memory with a number of small figures, which measure less than the margin of error. By combining the figures already given in detail we have the approximate total cost of the two classes of canals.

To the figures so obtained, an addition has been made of 20% to cover the various incidental expenses and contingencies. The incidental expenses are understood to include engineering, policing and sanitation; in fact, all the expenses on the Isthmus which would not be borne by the contractors. They are not supposed to include any expenses of a home office or of interest during construction. This percentage is double that usually applied in estimating the cost of work in settled countries where risks are not unusual.

Tide-Level Canal.—The cost of a canal on this plan would be approximately as given in Table No. 3.

TABLE No. 3.—COST OF TIDE-LEVEL CANAL.

Chagres Section, Colon to Obispo	p. 161	$90 000 000
Culebra Section, Obispo to Pedro Miguel	p. 174	90 000 000
Miraflores Section	p. 176	2 500 000
Pacific Maritime Section	p. 175	8 000 000
Miraflores Lock	p. 176	5 000 000
Alhajuela Dam and Railroad	p. 176	3 000 000
Diversion of Panama Railroad	p. 180	500 000
		$199 000 000
Engineering and Contingencies, 20%		39 800 000
Total		$238 800 000

Nearly the entire cost of this canal will be for excavation.

Lock Canal.—The estimated cost of a canal with locks, as described in this paper, the summit level varying from 85 to 90 ft., with three locks on each side, six in all, will be as given in Table No. 4.

TABLE No. 4.—Cost of Lock Canal.

Atlantic Maritime Level, Colon to Tiger Hill	p. 175	$11 100 000	
Tiger Hill Level	p. 174	5 000 000	
Lake Bohio	p. 162	1 000 000	
Culebra Cut	p. 174	43 000 000	
Miraflores Level	p. 174	800 000	
Pacific Maritime Level	p. 175	8 000 000	
			$68 900 000
Bohio Dam	p. 176	$2 000 000	
Gigante Spillway	p. 177	1 200 000	
Locks	p. 177	29 000 000	
Obispo Gates	p. 178	300 000	
Tiger Hill and Miraflores Spillways	p. 178	100 000	
Diversion Channels	p. 178	2 000 000	
Diversion of Panama Railroad	p. 178	1 300 000	
			35 900 000
			$104 800 000
Engineering and Contingencies 20%			20 960 00
Total			$125 760 000

The cost, therefore, of completing the Panama Canal on the lock plan would be about one-half that of completing it on the tide-level plan. This, however, does not tell the whole story. Neglecting the percentages for contingencies, all but $18 000 000 of the $199 000 000 estimated for the tide-level canal is for excavation. Of the $46 000 000 estimated as the cost of the Culebra Cut, in the high-level canal, $9 600 000 is for retaining walls along the sides of the cut; this reduces the cost of excavation to $59 000 000, or approximately three-fifths of the total cost of the canal (percentages still being omitted). In other words, although the cost of the tide-level canal is only about double that of the lock canal, the cost of excavation in the tide-level canal is about three times the cost of excavation in the lock canal. Excavation represents work which must be done entirely on the Isthmus. Much

of the cost of special structures represents material which would be manufactured elsewhere. If it be assumed that one-half the cost of the special structures represents work on the Isthmus, it may be said, in a general way, that four-fifths of the cost of the lock canal and the whole cost of the tide-level canal will represent work on the Isthmus. As the tide-level canal will cost twice as much as the lock canal, the amounts to be expended on the Isthmus for the two canals will be approximately as five is to two. The number of workmen required on the Isthmus, as well as the time required to complete the work, will be determined by these conditions.

The tide-level canal will have to be completed before it can be opened to traffic, the only postponement being in a portion of the cost of the special structures, which is insignificant. The lock canal can be opened with the second set of locks unfinished, and before the channel in Colon Harbor is deepened. This will reduce the expenditures required before opening the canal to about $92 000 000, without the percentage, or to a total of $110 000 000.

These estimates are based on the conditions now existing at the Isthmus, advantage being taken of the work which has been done there by the French and of the Panama Railroad. The work done by the New Panama Canal Company is practically all effective. Much of the work done by the old company is valueless. The canal which was excavated through the low country was taken out with a bottom width of 22 m. and a depth of 9 m., and the material was wasted close to the banks. To construct a canal of the increased dimensions now required will involve rehandling the spoil banks. Furthermore, the plan proposed in this paper would utilize the canal between Gatun and Bohio only as a channel for the Chagres, for which purpose it is of great value. The value of all this work, including the railroad, was estimated by the Isthmian Canal Commission at $40 000 000, which sum the New Panama Canal Company of France, and the official liquidator, representing the shareholders and creditors of the defunct Universal Interoceanic Canal Company, have agreed to accept as the price for which they will deliver everything they now own on the Isthmus, together with their records, maps and other papers. If this is added to the foregoing estimates, the cost of the tide-level canal would be about $280 000 000 and that of the high-level canal $166 000 000, exclusive of interest during construction.

Conduct of Work.

The first thing to do is to clean up the Isthmus, to provide sewers where feasible, and sanitary rules everywhere, to furnish the entire line with good water, of which a great abundance may be had at moderate expense, and to compel the employees on the canal to drink nothing else. This will take at least a year.

The plans made by the New Panama Canal Company were unusually complete for any preliminary work of this kind, but they were for a canal of different dimensions, with many details which would not be acceptable to American builders. The plans and examinations of the Isthmian Canal Commission were made for purposes of comparison and preliminary work rather than for actual construction. The final working designs remain to be made. Specifications must be prepared and all the necessary preliminaries which precede the letting of so great a work completed. Both the home and local organizations must be perfected. Much of this work can be done simultaneously with the sanitary preparations, and will take as long. A year spent in preparation, before the contracts are let, will save time in the end.

After the contracts are awarded, the contractors should be allowed another year to perfect their preparations. This is little enough time to provide for the organization of their forces and the purchase and collection of their machinery, much of which will have to be made after the contracts are awarded.

In two years after the transfer of the French property and the beginning of American occupation, actual construction work should fairly begin. The one greatest single piece of work is the Culebra Cut, and the time required to complete this cut will be the time which it will take to build the canal. All other work should be laid out with reference to this, so that, when it is completed, there will be no unfinished work to delay the opening of the canal.

The bulk of the laborers must be West Indian negroes, from Jamaica and perhaps some other islands. Skilled labor must come from the North, and generally be white. The methods of work should be so designed that the number of skilled workmen shall be as small as possible, and that they shall be protected from rain and sun when at work. It will probably be expedient to use electric power instead of steam as far as possible. A dam at the site of the Alhajuela Dam would furnish the power. If electric shovels could be used

instead of steam shovels, but one skilled man, instead of two, would be required at each shovel, and the heat from the boiler would be avoided. The debilitating influences of the damp, warm climate remain, and a system of furloughs must be arranged which will permit the white employees to recuperate in northern climates at least once a year.

The French companies were private corporations, working with no greater powers than those derived from their concessions. All this will be changed when the work becomes a Government undertaking. The powers of the United States will be those of military occupation, under which a sanitary control and discipline can be exercised, which should remove the greatest difficulties which have hitherto beset the Isthmus of Panama.

DISCUSSION.

M. MEIGS, M. Am. Soc. C. E. (by letter).—This extremely interesting paper on the Panama Canal and its problems will appeal strongly to all engineers, and no doubt awaken wide discussion. So far, the writer has not been able, from the discussion on the papers on the Isthmian Canal problem he has seen, to discover whether the Chagres is a mountain torrent of clear water, rolling stone, gravel and sand along its bed, or a silt-bearing stream, charged with mud as well as sand. In his opinion, there is a vast difference between the two, not alone as affecting the cost of the up-keep of the canal, but also the practicability of the scheme, now little talked of, for a sea-level canal, and as related to the problem of the Bohio Dam. Mr. Meigs.

The writer has had twenty years' experience on a canal, 7½ miles long and 250 to 350 ft. wide, on the Mississippi River, at Keokuk, Iowa. This canal receives the, at times, muddy water of the river, necessary to feed it and to provide for lockage; and, in addition, two small creeks and a few short watercourses empty directly into the canal. The rainfall in this latitude is only 40 ins., as against 200 ins., or thereabout, on the Isthmus, and yet it requires the almost constant attention of a dredge to keep the channel open for navigation.

In the twenty years of the writer's connection with the canal, 1 600 000 cu. yds. of mud, sand and gravel have been removed from the canal prism in a length of not more than 5 miles; two deep pools at the lower ends of reaches of the canal not yet having shoaled sufficiently to require dredging, and aggregating about 2 miles of the 7½ miles of canal.

On several occasions a single storm, lasting not 24 hours, has thrown enough material into the canal to keep a large Osgood dredge at work for a month removing it, working night and day 16 out of the 24 hours. It would seem that any sea-level plan would be negatived by the dredging requirements necessary to keep the channel open. With a 32-ft. boat it would require but a small rush of water from some side stream to cause a stoppage of navigation. The sea-level canal, necessarily, would be the recipient of all the débris washed down the tributary streams. A large rock rolled into the channel would cause the sinking of the first heavy-draft steamer that came along, and, in fact, the delays and expense would be interminable.

At the Keokuk Canal a sluice in the upper level allows of a short tow for the dredge tender, as the sluice is used to wash the dredged material into the river by opening certain gates. At Panama there would seem to be no method of getting rid of the material dredged except by elevating it to the sides of the canal, or by towing it out to sea. Either of these methods would be slow and very costly.

Mr. Meigs. Even if there is clear water at all times, there will be, for a sea-level canal, constant trouble at the mouth of every creek and river. It is true that dams along the course of these streams would retain a portion of the débris for a time, but they would soon fill up, and dredging would have to be the result in the end. This has happened already to the Keokuk Canal. From a dredging standpoint, the sea-level canal looks like an impossibility.

All this is changed in the admirable high-level reservoir and lock scheme worked out by the Canal Commission and Mr. Morison. Whether bearing silt, or only sand and gravel, Lake Bohio will perform a most valuable office in providing a settling ground for the water used in the canal. No doubt the greater part of the sediment will remain in the lake, and the necessity for constant dredging in the canal prism will be avoided for a long time.

Mr. Morison's design for a temporary dam seems to the writer to be sufficiently good for the permanent structure. There seems to be no reason why iron should not be adopted as the material for permanent and high dams. It should be remembered that such a dam as sketched in Mr. Morison's paper on "The Bohio Dam" can be made absolutely tight. The construction would afford a view of the lower side of the dam at all times, and all leakage could be detected and stopped at any time. If kept painted, it would rust only on the upper side, and the rate of deterioration would be very small. Wrecks of vessels thirty years and more under water, on the upper part of the Mississippi River, show in their ironwork but little loss from rust. A brown scale is formed on the surface, looking like brown varnish, and this seems to protect the iron.

If the dam were built early in the progress of the work, would it not, by means of the lake, give a cheap means of transporting the spoil from the prism of the canal? That spoil, dumped from barges above the dam, would, in the course of the construction of the canal, fill the valley, and would make a dam that would be absolutely beyond suspicion, and at little comparative expense where the work is almost entirely a cut. As for percolation, it would cut that off entirely, for it seems to the writer that the percolation has been more dreaded than there is any occasion for. If Mr. Morison's iron dam were merely set upon a broad sheet of concrete extending some distance above the dam, and the bearing under the dam were fortified by driving plenty of round piling to give a firm foundation and also to consolidate the soil; if this dam were built between abutments of stone, with an earth embankment beginning at the point where it would be possible to reach bedrock with caissons, thus securing a tight connection with the bottom of the geological valley; and if, under the sheet of concrete, several rows of sheet-piles, preferably of iron, like the dam, were driven across the valley from one abutment to the other, the writer thinks that the

foundation of the dam, and the percolation beneath it, would be sufficiently guarded, without having to go to the unparalleled depth for foundations, which, in the minds of many engineers, seems to be necessary. There are, in India, tanks, as they are called, which are formed by earth dams of heights equal to the Bohio Dam, and they have stood for centuries. Some of these dams, it is said, were built by sluicing material from the adjoining hills in troughs fed by the mountain streams in the vicinity. It is not likely that the people who built those dams went into refinements about bed-rock foundations. Mr. Meigs.

On the section marked *B**, on the map of dam sites, it would seem, from rough calculation, that a dam might be constructed consisting of 350 ft. of embankment at each end and a connecting section of iron, not more than 550 ft. long. This iron dam would be about 100 ft. high, but what better or more trusty material can be found? The calculation of the forces entering into the problem are simple, too; much simpler than in the case of a bridge, and the material would be used economically. The work could be done in a temperate climate—all but the setting up—and, during erection, the river could be allowed to flow between the bents until the final moment of closure. It is this feature—of doing most of the work in high-class shops and shipping it out ready to erect—that most commends itself. Finally, if this dam were erected early, and, on being tested, were found wanting, it could be replaced with some other structure, without interfering with the opening of the canal. The writer cannot help thinking that Mr. Morison's estimate for the earth dam is too low, though, if built, it would certainly solve the problem.

THEODORE PASCHKE, M. Am. Soc. C. E. — Mr. Morison's plan for a tide-level canal, as outlined in his excellent paper, is a very attractive one, and must appeal to all engineers and others who take any interest whatever in the question. Mr. Paschke

Heretofore, the control of the Chagres River, has been the great stumbling block in the way of a sea-level canal. The International Technical Commission, under the leadership of the genial de Lesseps, in declaring for a sea-level canal at Panama, certainly showed no lack of boldness in conception or assertion. But "'twas easier said than done."

As far as the writer is aware, no tangible, practical plan for the control of the Chagres, beyond a proposition to dam the river at Alhajuela and divert its waters, from the reservoir thus formed, through a new channel to the sea at a sufficient distance from the canal, had been evolved. The managers of the enterprise at Paris evidently depended upon the many eminent engineers who were sent out to the Isthmus to solve the problem in all its working details on the spot.

These, in turn, for the most part unused to accommodating them-

* "The Bohio Dam." *Transactions*, Am. Soc. C. E., Vol. XLVIII, p. 239.

Mr. Paschke. selves to the new and strange surroundings, unnerved by the debilitating influence of the climate, and over-awed by the apparent impenetrability of a tropical jungle and the magnitude of the problem before them, threw up their hands in despair and either fell victims to the pernicious fevers, or, if survivors, were subdued in spirit.

The rest of the story—the prodigality of the management, the subsequent exhaustion of funds and the final abandonment of the sea-level canal in favor of a lock canal—is a matter of history, and needs no further mention.

This grand failure to make good the decree of the International Technical Commission has been like a ban upon the project of a sea-level canal with the majority of engineers ever since. Therefore, it is refreshing and reassuring to have an engineer of Mr. Morison's standing come out with a proposition for a tide-level canal on entirely new lines; on lines of such bold simplicity that at once they not only assure the feasibility of the plan, but call forth an unstinted admiration for the author's sagacity, and give evidence of his fitness to deal with such problems.

The plan, as outlined in the paper, seems to have been left, probably intentionally, in a somewhat incomplete form, so as to invite criticism and discussion. As far as the plan is outlined by the author, the speaker has no criticism to offer, but only desires to point out certain natural conditions and features in connection therewith, which, when properly adjusted, may tend to assist in making those outlines a little more definite.

Mr. Morison, by calculations based upon reliable data, regarding the discharge of the Chagres River, has drawn the conclusion that it would require a canal 400 ft. in width to accommodate the maximum ordinary flood discharge without injury to the canal; with the reservation that this width might prove inadequate for a repetition of a flood like that of 1879. On this the speaker has only one comment to make, and that is: Why draw the limit at a width of 400 ft.? Having gone that far, it would be as well to go a little farther and obtain an adequate factor of safety. However, the speaker quite agrees with Mr. Morison that the construction of a dam at Alhajuela would be a more rational measure, not only for the control of the Chagres waters, but for another reason to be mentioned directly.

Mr. Morison has given the average elevation of the bed of the Chagres at Gamboa as 45 ft. above tide level, and the elevation of the bottom of the canal as 35 ft. below. This makes a fall of 80 ft. from the bed of the river to the bottom of the canal. A discharge of 70 000 cu. ft. per second over a precipice 80 ft. high almost makes one think of Niagara. It is plain that something must be provided to meet this condition. Some sort of a receiving basin or pool, of adequate dimensions, will have to be excavated, to bring the waters to rest, so that they may enter the canal quietly.

Mr. Paschke.

The contemplation of this feature naturally leads to another question: What becomes of the detritus and the sediment brought down by the river during floods? How is that to be taken care of?

It is to be regretted that so little consideration has been given this subject by the various commissions and engineers who, of late, have reported and written upon the problem of an Isthmian Canal. This subject is a very important feature in any proposition for the control of the Chagres River, and, if ignored in the formulation of the plans, will force itself, sooner or later, upon the operators of the canal when completed. It would be well to have some systematic observations upon this subject made during the coming rainy season, to ascertain the amount and character of the sediment carried in suspension by the Chagres River during floods.

The topography of Central America has a character peculiar to itself. It is volcanic, throughout. The underlying rocks are covered with deep layers of volcanic ashes or dust, of varying fineness, giving the country, in its principal features, a soft, undulating profile, which is only pierced here and there by groups of volcanic cones, for the most part now silent, but bearing witness of a former activity.

The accentuations which occur in the landscape are principally due to the action of water. This action of furrowing the surface and deepening and widening the cañons or barrancos down to bed-rock is still going on, and may be observed in any of the mountain streams during a flood. An inspection of the steep banks will reveal, like an open book, the character and thickness of the various layers of volcanic dust or ashes, and give in unmistakable language an account of the magnitude of the process necessary for the formation of these covering strata. With the exception of a few isolated cases, very little evidence has come under the speaker's observation to show that in the latter part of the eruptive period of that country, flows of liquid rock or lava have taken place. It seems that during this period, the eruptive material has only been ashes or dust, or these materials mixed with water as liquid mud. This latter observation has been verified by the many traditions among the aboriginal inhabitants relating to water- or mud-throwing volcanoes.

Most of this volcanic material has attained a certain consistency, a certain degree of hardness or cohesiveness, which allows it to stand, when pierced by an excavation like that for a railroad cut, with a slope approaching very nearly to the vertical. In fact, the speaker's experience has been, that the nearer to the vertical the faces of these slopes are kept, the better they stand, provided the surface drainage above is properly taken care of. The reason for this is, that, in the first place, it is a characteristic of most of this volcanic material, that its surface, when exposed to atmospheric influence, hardens slightly, giving it a crust-like protection; secondly, the nearly ver-

Mr. Paschke. tical face is not exposed to the action of the tropical rain torrents to such an extent as a face at the ordinary and customary slope of 1 to 1. However, on the other hand, all this material yields easily to erosion by flowing water. This may be traced out readily in any of the mountain streams of that country.

When exposed to the action of flowing water this material is reduced quickly to its original form, the coarser particles, in the form of sand, are carried down stream, a varying distance, but the finer particles, which in some cases form by far the greater portion of the mass, are carried off in complete suspension, in which condition they are held for a long time. Even when the speed of the flow has slackened or has come to a practical standstill, as in the case of a stream emptying into a lake or reservoir, the process of deposit is slow.

All accounts and descriptions of the physical character of the Isthmus of Panama agree that it is volcanic, and the speaker's observations, made while crossing the Isthmus on two different occasions, confirm the view that the general description of the covering strata of Central America, just given, applies also to the Isthmus, possibly in a somewhat less marked degree. A deduction that the Chagres River is no exception, in this respect, to any of the larger Central American rivers which have come under the speaker's close observation, would seem to be entirely logical. An inspection of the river beds of that region at any appreciable elevation above sea level, where the flood waters are entirely confined by the banks, will fail to reveal evidences of the quantity of fine silt carried by their flood waters, for the reason that nothing but portions of the coarser particles—the sand and gravel—remain, the finer silt particles are carried down stream in suspension, and, if the flood is not large enough to overflow the lower banks, are carried to the sea.

Returning now to the discussion of the tide-level canal, it is to be observed that the proposed dam at Alhajuela will serve most admirably the two-fold purpose of controlling the flood waters and detritus brought down from the upper valley; but, even so, one is confronted by the fact that there exists the tendency to silt up this reservoir in time. And if the control of the Chagres waters depends upon the unimpaired capacity of this reservoir, then its gradual silting up is a serious condition, and must be reckoned with by the designers of the canal works.

From Alhajuela, at the foot of its dam, to Gamboa, where the river strikes the canal, is about 7 miles, according to Mr. Morison's statement. Some tributary streams empty their waters into the Chagres here, and their united waters, by the time they arrive at the canal, will be highly charged with sediment. The proposed receiving basin at this point, mentioned before, can be made a settling basin by enlarging it and deepening it somewhat below the bed of the canal. By

periodical dredging, this basin can be kept clean, and in this way the water entering the canal will be freed of all coarser sediment. How much of the finer particles of silt would be deposited in the canal, under the varying conditions of current speed, will be, at this time, for want of reliable data on this subject, purely a matter of conjecture. If the speaker were to venture an opinion, it would be, that the quantity deposited under these conditions would be proportionately insignificant, and insufficient to cause doubt as to the feasibility of the plan. Mr. Paschke.

Again, if the arguments just advanced are applied to the plans for a lock canal, and to Bohio Lake in particular, the conclusion is evident that something must be done to prevent the lake from silting up. Two ways suggest themselves, which, singly or in combination, would effect a partial remedy. One is that the dam proposed to be built at Alhajuela for the tide-level canal would do the same service for the lock canal. The other would be to reserve the part of the lake from Alhajuela to Gamboa for a settling basin, to be kept clean by periodical dredging.

In both cases, though, we are confronted with the ever-existing danger of the final silting up of the lake by the finer material which cannot be precipitated in the settling basin; however, with the ameliorating condition, that the process will be an exceedingly slow one.

This fine silt, held for considerable time in suspension, will infuse itself throughout the waters of the lake and finally settle to the bottom, covering it with a sheet-like formation of fine, slimy silt, which, reinforced at every flood, will make, in a comparatively short time, a most effective waterproofing, insuring against all seepage and making it unnecessary to introduce sheet-piling of any sort.

This theory is based upon long and exhaustive observations made, and experiences had, by the writer, with mountain-stream flood waters in other parts of Central America, and, if the waters of the Chagres do not differ radically from those of neighboring localities, will hold good here.

It is extremely gratifying to note how the authorities who direct the affairs of our Government, have, unerringly, with great tact and tenacity of purpose, steered the Isthmian Canal project safely through a sea of contradictory counseling, biased opinions, misrepresentations, contending private interests, etc., and landed it at Panama, the point on the Isthmus where, by right of natural selection, the canal should be built.

The Isthmian Canal Commission has recommended ostensibly a lock canal, admitting that a sea-level canal can be built on the Panama route.

To construct a lock canal, where a sea-level canal may be built for only the sacrifice of a little more money and time, in other words, to

Mr. Paschke. accept a substitute for the real article because it is cheaper, does not seem to be in line with the tendencies, aims and capabilities of this young, but growing, giant nation.

It would be interesting, indeed, if some of the engineers who are members of the Isthmian Canal Commission could or would give some idea regarding the feasibility, and probable cost, of the so-called diversion of the Chagres River from the Alhajuela Reservoir, as proposed by the old de Lesseps Company.

If this is at all feasible, and the cost not so great as to be prohibitive, under the present circumstances, then it would seem that this plan should stand first on the list for consideration. On the other hand, should the plan be found impracticable, then, certainly, the plan for a tide-level canal, as outlined by Mr. Morison, deserves serious consideration by the Commission.

Mr. Harrison. C. L. HARRISON, M. Am. Soc. C. E.—The question whether the canal across the Isthmus of Panama should be a sea-level canal, with only tide locks, or a high-level canal, with a number of locks to reach the summit level, has been a subject of discussion ever since the project was first proposed. The author has presented some of the difficulties involved in constructing a sea-level canal, but there are still others which can be inferred, but may be more specifically mentioned. If the Chagres River is taken into the canal at or near Obispo, then the canal from this point to Colon must be large enough to take the flood volume of the river at Obispo, and, in addition thereto, all the tributary streams between that point and Gatun.

Assuming that the depth is 35 ft., bottom width, 400 ft., with side slopes of 2 to 1, and that the discharge of the river is 100 000 cu. ft. per second; then, in the canal from Obispo to Colon there would be a surface slope of from 12 to 14 ft., and a mean velocity of more than 4 miles per hour, and perhaps a maximum velocity of 6 miles per hour, in parts of the canal. If this flood volume were to be of frequent occurrence or long duration, it might be advisable to make a larger channel and thus reduce the slope and the velocity of the water in the canal. But there is another phase of the subject which must be considered, *viz.*, sedimentation.

A channel of the foregoing dimensions would have, at low water, a cross-section of 17 450 sq. ft. If the discharge were 17 450 cu. ft. per second, then the mean velocity would be 1 ft. per second. At such a velocity the very fine particles of material suspended in the water would settle to the bottom of the canal, and sand would be deposited when the discharge was 50 000 cu. ft. per second. It is probable that a greater discharge than this would carry the suspended matter out into the bay at Colon, and, in addition, scour out some of the deposit which had been made at lower stages of the river. The net result of this would be that nearly all the sediment carried by the

Chagres River would have to be dredged out of the canal between Obispo and Colon, or, out of the Bay of Limon at Colon, which would make the cost of maintenance very great. Mr. Harrison.

The author estimates that "the time in which the discharge at Gamboa would exceed 35 000 cu. ft. per second, or that at Bohio 50 000 cu. ft. per second, would probably not be more than ten days in twenty years." This would mean that there would be some sedimentation in the canal at practically all times; but there are no data to determine the quantity of suspended matter carried in the water or the quantity of sand and gravel moved along the bed of the river by the force of the current. At low and medium stages of the Chagres the water is not nearly as muddy as the Mississippi River above St. Louis, and carries less sediment than the Hudson River above Troy. The speaker has not observed the condition of the Chagres at flood times. Whatever this quantity may be, it is certain that a large part of it would have to be removed from the channel by dredging. This is by no means a difficult thing to do, but it is an item of cost for maintaining the channel.

In the sea-level canal it would also be necessary to provide some special method of taking into the canal all the streams from Gatun to Obispo. Much the largest of these is the Chagres at a point near Gamboa. The flood discharge at this point may vary for different years from 30 000 to 100 000 cu. ft. per second, and it must be conducted from the river, which is about 75 ft. higher than the bottom of the canal, into the canal in such a way as not to produce cross-currents which would impede navigation or erode the banks. This would require the construction of a dam across the river, together with an apron down to about the level of the bottom of the canal, and then the excavation of a new channel from this point to the river, on an alignment that would cause it to enter the canal in a direction nearly parallel to it. If this dam and the channel leading from it to the canal were not built, then the slope of the bed of the Chagres would be readjusted for miles up stream, and all material eroded in this readjustment would be deposited in the canal and would have to be removed by dredging.

These structures, for controlling a flood volume of 100 000 cu. ft. per second, would be very expensive. The cost would depend on the character of the foundations to be had and the kind of structure to be built, and also upon the distance the dam would be located up stream from the canal. The data are not at hand for designing these structures and estimating their cost, but it is certain to be a large item. Similar provision must be made for taking into the canal all the streams between Obispo and Gatun, but they are small compared with the Chagres. It may be that the author has included these two items in his estimated cost for a sea-level canal; but if he has not, then they

Mr. Harrison.

may properly be added. Independent channels for the canal and the river would avoid these difficulties, but, unfortunately, no safe location for such a river channel has yet been found that could be constructed at a reasonable cost.

From a personal study of the situation, the speaker believes that the summit level, as proposed by the author and the Isthmian Canal Commission, with the long spillway at Gigante, is the best solution of the problem. It makes the control of the much-dreaded Chagres both easy and certain.

In the author's estimate of cost, 20% is added for engineering, policing, sanitation, and all other expenses not included in the unit prices for the various classes of work. This may seem excessive to those not familiar with the climatic conditions and the work to be done. The canal is located in a tropical country, which is hot for twelve months in the year and wet for from eight to nine months. Exposure to the night air or the midday sun is almost certain to produce sickness in the unacclimated peoples of the North, from which all the technical talent must be secured. In this climate, work and all other things must be done in moderation. It will require twice as large an engineering force as similar work would require in this country. The water supply and sanitation must be provided and maintained, which will be an item of considerable cost. The brush and timber must be cut and burned on the entire area of Lake Bohio, which is about 40 sq. miles. Should this not be done, the dead timber would float in the lake, impede navigation and interfere materially with the operation of the locks. The allowance of 20% seems to be too small, rather than too large.

In the first paragraph on page 183, the author has outlined briefly a most important feature in the "conduct of the work," which, to neglect, is but to invite disaster, great increase in the cost of the whole work, and longer time for its execution.

There are but two seasons known on the Isthmus, the wet season, which is generally from May to January, and the dry season, which is generally from January to May, though in many years either of these seasons may begin earlier or later than the months above mentioned. The domestic water supply during the wet season is collected in tanks from the rain which falls on the roofs of the houses, and this, usually, is pure and always abundant, for it rains every day; but during the dry season the water is obtained from occasional rains and from water which was stored in the tanks during the wet season. The result is that the better class of people has a sufficient supply to last through the dry season, but the laboring class does not, and secures water from the most convenient streams or swamps. The dry season is usually considered much more healthful than the wet season. While on the Isthmus, as Chief Engineer for the Isthmian Canal Commis-

sion, the speaker collected health statistics which showed that the sickness and death rate were much greater during the dry season than during the wet season. An analysis of these statistics revealed the fact that in the dry season there was less sickness among the better classes of people and more among the poorer classes. This, no doubt, was caused largely by the different water used for domestic purposes during that season, and points to the great importance of having good water at all seasons for everyone. It is equally important to provide efficient sanitation at all times. If a good domestic water supply and proper sanitation are not provided, and an epidemic should break out during the first year of active operations on the Isthmus, it would not only result in great loss of life, but it would be exceedingly difficult and very expensive to secure an adequate force of workmen to complete the construction within the time contemplated. Mr. Harrison.

The author, in the closing sentence of his paper, very forcibly states the sanitary conditions under which he expects the work to be done, and his estimates of cost are evidently based on such conditions.

The Isthmian Canal Commission, in making its estimate of cost, contemplated perfect sanitary and police control. From page 261 of its report, the following is quoted:

"A considerable population has long existed on the Panama route, and it lies on a pathway of comparatively large trade, along which currents of moving people from infected places sometimes converge, thus creating conditions favorable to epidemics."

These conditions may be somewhat worse when a great many laborers are employed in building the canal. From page 262 of this report the following is quoted:

"In order to exercise the rights necessary for the construction of the canal and for its management after completion, the United States should acquire control of a strip of territory from sea to sea sufficient in area for the convenient and efficient accomplishment of those purposes. Measures must also be taken to protect the line from unlawful acts of all kinds, to insure sanitary control, and to render police jurisdiction effective. The strip should be not less than 5 miles wide on each side of the center line of the Canal, or 10 miles in total width."

The treaty made recently between the United States and the Republic of Colombia for the construction of the Panama Canal, gives the United States sanitary and police control over a zone of territory about 3 miles wide on each side of the center line of the canal, or a total width of about 6 miles, which is a material reduction from the 10-mile zone recommended by the Commission. But this restriction is not as objectionable as placing the control of the towns of Colon and Panama, which are within the 6-mile zone, under the joint control of the native and United States authorities. It would be better if the control, during the time of construction, were vested solely in the United States. Everyone coming to the Isthmus will pass through

Mr. Harrison. one or the other of these ports, and their inhabitants would be the first to be exposed to any contagious or infectious diseases brought to the Isthmus from other countries. It is important that the towns should be put in the very best possible sanitary condition and kept so during the whole time the work is being done. Enforcement of the regulations for this purpose would be easier under single than under dual control.

Mr. Crane. W. E. CRANE, Jun. Am. Soc. C. E.—That part of the discussion relating to the Pacific terminal of the canal has interested the speaker very much, and he would like to suggest to the author that it should be discussed further.

The length of the canal is approximately 43 to 45 miles, and the coastal plain on the Pacific Coast is about 6 miles in width. It may be assumed that the distance thus taken is measured from mean high water on the Pacific Coast to mean high water on the Atlantic Coast. The City of Panama is situated on a point, and its elevation is but a few feet above the Pacific Ocean. At extreme low tides, there is exposed a mud flat extending into the ocean 3 to 5 miles, possibly a greater distance. Coast line vessels anchor near the three islands which are from 4 to 5 miles from the Panama dock. The terminal of the canal is about 2 miles along the shore above Panama.

The speaker visited this section of country in 1896, and remembers a discussion, on the day he was at this terminal, relating to the direction and distance from the shore line to deep water, the width and depth of excavation, and the method proposed for protecting the banks, the probable cost of this section, what action the winds and waves would have on the banks of the canal, and how much dredging would be required annually in this section of the canal.

Mr. Harrison has mentioned this portion of the canal, but only as to the depth advisable to permit vessels (especially war ships) to enter the canal at extreme low tide.

A further discussion of the Pacific terminal, by members who understand the conditions and have had access to the plans and estimates, would be very interesting and beneficial.

Mr. Ehle. BOYD EHLE, Assoc. M. Am. Soc. C. E.—As usual, Mr. Morison, in his statement of facts, has left little to be said. In the discussion, however, certain statements have been made which do not agree with the speaker's knowledge of actual conditions observed on the Isthmus at various times in years of service on the surveys and canal work.

The Chagres is not subject to great scouring action, and there cannot be many of the dangers predicted regarding the silting up of the channel. Above Alhajuela the Chagres is simply a mountain stream, running part of the way through rocky gorges. The soil is not a lava ash, as has been assumed, but is a clay held in place by the rank vegetation of the tropics. Below Alhajuela and nearer to the canal

location there is some alluvial soil, but of no great extent, and this, in the case of a lock canal, would form part of a lake bottom, and would not be affected by the slight current to which, in Lake Bohio, even the great floods will be reduced. Mr. Ehle.

Although the lock plan provides a certain solution of the flood problem, by the use of the Gigante Weir, the question is often asked, "Why not divert the Chagres to the oceans"? This was examined closely enough by the Panama Canal Company to show that there were no evident possibilities in that line. Surveys were made to find the shortest tunnel line possible, but the results gave no hope of anything feasible and economical, and the idea was abandoned.

The Tiger Hill cut-off undoubtedly has some merits not possessed by the river line, and these, as stated by Mr. Morison in a preliminary way, will lead probably to its thorough examination in the future. It could not be incorporated in the careful and conservative report of the Isthmian Canal Commission, it is said, on account of the lack of data. This will not be against it in a future study, and its merits and disadvantages will no doubt be weighed properly by the Commission before actual construction is started.

The solution of the canal problem by the construction of a sea-level canal has never appeared to the speaker as an engineering solution, as engineering is usually defined. There have never appeared to be any compensating advantages for such an excessive extra expenditure of money and time, and none appears to have been stated clearly and sustained.

Nature, through the tides, makes one lock necessary, and that, during most of the time, is the check on the canal's usefulness, as surely as more locks, provided they are in good order. The time gained in doing away with the locks is insignificant in comparison with that required for the long journey around The Horn which the lock canal will save. It cannot have any recognizable value, as far as can be seen in the future. When it has such a value, probably canals will not be necessary, and the air, instead of the water, will be the highway of communication. It is true that locks are likely to be deranged, but should not, as an engineer's work, be likely to fail; besides, as a precautionary measure, the plans of the Commission provide for twin locks.

The question of a sea-level canal is not an imminent one, as it is perfectly feasible to cut a lock canal to a sea-level canal at any time in the future, if so desired; and it can be safely left to the engineers of the future to decide whether a sea-level canal is required.

It seems that all the schemes for the control of the Chagres in relation to a sea-level canal were never worked out in detail. There was much procrastination on this problem by the French Company, and their tardy plan, after the failure of the first company, has never re-

Mr. Ehle. ceived any very enthusiastic encomiums from the engineers who have reviewed it.

A sea-level canal would be exposed to all the troubles produced by the great floods of the Chagres, with little chance for any protection. One scheme for the control of floods, however, would be the Tiger Hill location, which would take the canal out of the lowest part of the valley and into a safe position from Bohio to Colon.

The decrease in the height of the locks would seem to be desirable if contrasted with the loss of time incident to the operation of an extra lock, as a proper measure of conservatism, provided no serious difficulties were encountered in its construction.

Another point is that of decreasing the cost on the Pacific side by taking advantage of the rise of the tide. This would seem to be a proper utilization of Nature's forces—as much so as a switch-back over a mountain before a railway is built through it. Why not try it? A few hours of time are nothing compared with the days of steaming by the *Oregon*. When the demand becomes imperative, and the few hours saved would mean a proper return on the outlay, then build it as deep as such value will justify.

As to the case of a fleet, in the rare event of war, being at a disadvantage if divided by the fall of the tide, it appears that the enemy would be in as great trouble; however, that is a very remote contingency.

Mr. Burr. WILLIAM H. BURR, M. Am. Soc. C. E.—In this paper Mr. Morison has, among other things, set forth in deserving prominence some of the salient features of the Isthmian Canal Company's plan for the Panama Canal and his proposed modifications of them, which latter were also mostly, if not entirely, fully considered by the Isthmian Canal Commission. There is obviously a little delicacy in entering into the discussions in much detail which took place in the Commission regarding these or other matters, and it is the speaker's purpose to consider, as any member of the Society may, only the salient engineering features of the matter. It may be said with propriety that the shortened line between Bohio and Colon was considered carefully by the Commission, but only a limited examination was given to it in the field. This line is an old one, and was probably first proposed by Commander E. P. Lull, U. S. N. It possesses undoubted merits, and is worthy of careful consideration before final construction is undertaken, but in discussing this feature at this time two things are to be carefully borne in mind; the first is the incompleteness of the actual examinations made on this shortened route, and the second is the fact that a large amount of work has already been done on the French line between Bohio and Colon. It is hazardous to make an exact prediction of cost in the absence of necessary information on which to base it. Apparently, a comparatively small amount of money might possibly be saved

by adopting the Lull line, but that cannot be stated confidently in the absence of complete borings and other requisite examinations. A serious, but not insuperable, objection is the considerable amount of embankment necessary between Bohio and Tiger Hill. These embankments may reach the height of 25 ft., and possibly a little more. While such embankments may be made safe, and are entirely justifiable under conditions such as those existing in connection with the Nicaragua route, they certainly are not desirable, and they should be avoided unless necessity exists for them, or adequate compensating advantages are attained. Mr. Burr.

Again, the adoption of this shortened line and the Tiger Hill locks involves the loss of time by a vessel traversing the canal necessary to make the additional lockage. As the gain in distance is only about 1¼ miles, the increased time required to pass the lock would be far more than that necessary to make the added distance by the French line. The introduction of the additional lockage, therefore, would be a sensible loss of time in passing through the canal; in fact, so great a loss of time as to increase materially the time of passage over that required by the adopted line. In other words, for the purposes of navigation, the canal would actually be lengthened by the Tiger Hill line and lock. The additional lock would also increase the opportunities of accident at the lock gates, with the added chance of destruction of the short Tiger Hill level by an accident at the Bohio gates suddenly releasing the lower-lock volume of water.

If the work of constructing the canal were to be begun as an entirely new project, it is not unlikely that the shortened line between Colon and Bohio without a lock might be preferable to that on which so much has now been completed. With the conditions actually existing, however, it is the speaker's judgment that complete examinations along the shortened or Lull line would show little or no difference in cost of completion.

It is true, as Mr. Morison states, that the locks planned by the Isthmian Canal Commission are larger than those which have ordinarily been constructed, and yet such locks as those built at Sault Ste. Marie save the construction of the Isthmian Canal locks from being violent departures from precedent, even with their material increase of lift. The massive masonry construction and other large features of these proposed locks would probably frighten few civil engineers, nor do they involve sufficiently difficult operations either of design or construction to make it necessary to incur the construction of extensive embankments to avoid them. It is not unlikely that many, if not most, engineers would prefer to avoid the embankments by resorting to locks of high lift.

It has been shown, in the discussion of a proposed plan for the Bohio Dam by Mr. Morison, that the consideration of seepage involves

Mr. Burr. about as great uncertainties as can ordinarily be attached to engineering speculation, and, indeed, that no quantitative results can be predicted confidently in regard to it. Hence it is scarcely required to give detailed consideration to such a feature of the work. It may be stated, however, that it is not quite clear how the seepage under a dam at Bohio placed on porous material would be affected by the proposed Tiger Hill level. The total head between the surface of the water in Lake Bohio and that in the river-bed below the dam, or dam and canal, would remain unchanged, and as the seepage through such open and porous material would depend upon that head it could be modified only by the slightly lengthened seepage channel. The amount of seepage, therefore, cannot reasonably be supposed to be changed sensibly by this feature. Some recent experiences of the speaker, in connection with the seepage or flow of water through fine sand, or fine sand and silt, have impressed him in a marked manner with the danger attending the construction of a dam built on porous material, which he pointed out in his discussion on Mr. Morison's paper on "The Bohio Dam."

There are two other features of the modified canal plan brought out by Mr. Morison which may be treated largely as one, namely, decreasing the depth of excavation in the Culebra Cut by 3 ft. and the depth of excavation in the entrance channel of Panama Bay by 10 ft. The proposition to raise the bottom of the excavation in Culebra Cut 3 ft. to Elevation + 50, instead of retaining it at Elevation + 47, recommended by the Commission, would trench seriously upon the capacity of the canal for ships of the greatest draft. Obviously, it must be recognized that by far the great majority of ships passing through the canal will have considerably less than the maximum draft. At the same time it is also to be remembered that the purpose of this canal construction, as expressed in the language of the law on which the instructions to the Commission were based, is to afford accommodation for the greatest ships afloat. It is only reasonable to suppose that this expression meant complete accommodation and not partial accommodation during some seasons of the year or stages of the tide. This restriction in the canal would lead to seasonal restriction of navigation capacity, which, however, might be partially compensated or relieved by the construction of the Alhajuela Reservoir.

The decrease of depth of 10 ft. in the Panama Channel would be a daily restriction of navigation capacity, since the throttling effect of the diminished channel depth would occur at every tide. For one-fourth of the entire time the canal would be shorn of its greatest capacity. Even if it be admitted that the maximum delay of any ship would not be more than 6 hours, there are conditions under which that might be serious. This consideration carries with it greater gravity in that it would affect the largest ships.

Mr. Burr.

These features were considered most carefully by the Commission, but it seems to the speaker that the decision to plan a canal possessing the maximum prescribed capacity was wise and should not be departed from. If the United States Government is to complete a great canal across the Isthmus for the purpose of affording the freest waterway for ships, the accommodations provided should be subject to no throttling or other substantial restriction of a diminished canal depth at its central portion or at either extremity. Such material disadvantages would constitute objections so serious that the demand to relieve them would probably follow closely the opening of the canal.

The practicability of a sea-level canal across the Isthmus of Panama is much more real than has ordinarily been considered, as Mr. Morison shows, and as indicated so clearly in the report of the Isthmian Canal Commission. In the event of such a construction it would undoubtedly be wise to make the canal prism of such area of section as to receive the flood waters of the Chagres modified by the storage resulting from the construction of the Alhajuela Dam. The question of the area of the prism is in reality the greatest single question involved in the sea-level plan, and whether an area of section of even 15 000 sq. ft., mentioned by Mr. Morison, would be sufficient is not yet determined. Further, it is a serious question whether, even with an additional expenditure of $125 000 000 or more, and the greatly extended time required for construction, it would not be the part of real wisdom for the United States Government to undertake at once the sea-level plan, rather than the elevated plan, with its advantages of reduced cost and shortened time.

Mr. Bunau-Varilla.

P. BUNAU-VARILLA, Esq.—The speaker feels fully able to answer the questions which have been asked. In or about the year 1884 he started the first dredge to cut the channel in the Bay of Panama, and at that time it was the opinion of nearly all the people on the Isthmus that every bucketful dredged from that channel would be washed back at once. For that reason, Commander Lull, when projecting his line across the Isthmus, threw the entrance of the canal to the east side of the City of Panama in order to avoid the mouth of the Rio Grande, which is the point where the entrance is now located.

The work had been studied diligently by the speaker before he went to the Isthmus, and, on arriving there, he observed two facts which confirmed his opinion that the work would be successful and that the depth of such an entrance could be maintained. First, the entrance to the canal in Panama Bay is perfectly quiet, the little Bay of Panama being in a sheltered position within the larger bay, known as the Gulf of Panama, so that the heavy seas from the great storms from the Pacific do not enter it. The bay is remarkably still. Second, the sedimentation and consequent filling in of the bed of the channel in the bay would be caused by the simultaneous action of

Mr. Bunau-Varilla.

currents and waves; the waves put the sand and silt in suspension in the water and the currents transport it, and when an excavation is reached the suspended matter settles. Such a current exists; it flows continuously toward the west, but, owing to the complete and regular flow of water, there is practically no material in suspension.

Six months after the channel had been dredged it was examined by the speaker, who found that the depth in the center had been fully maintained. Although the side slopes were modified, the depth on the axis was fully maintained. This is proof that the work in the bay will be absolutely successful. The channel is already dug for a part of the distance, and ships enter and follow it. This question is not open; it is closed. It is not a question of the future; it is settled.

In relation to the question as to the lock canal and the sea-level canal, the speaker has no more fear of sediment in the latter than he has of sediment in the channel in Panama Bay.

The water of the Chagres does not flow through volcanic ground. The word "volcanic" must not be used. "Volcanic" ground means a ground filled with active volcanoes and which produce rock which is very soft and liable to decay very easily under the influence of the atmosphere. It is true that in a country where there are active volcanoes, the waters of the rivers carry an enormous quantity of sedi ment. The Isthmus of Panama was formed in remote times, before the human race appeared upon the earth, about the end of the tertiary or at the beginning of the quaternary period, and at the time these volcanoes were active, they did not eject lava, but that stronger material called basalt.

The rocks and clays of Panama are extremely stable, and, as a rule, the waters of the Chagres are pure and clean. Of course, during great floods there is a certain amount of erosion, but, at such times, if the water is received into the canal, there will be, also, an increased current, which will take up the silt washed in and carry it through the canal and out to sea. The speaker has no fear upon that point. Of course, there will be the work of maintenance, but, for a canal of that importance, what is it to take out 500 000 or 1 000 000 cu. m. every year? It is absolutely nothing. In the Suez Canal more than that quantity is taken out, and the Suez Canal has not been a failure, up to this time.

There is another very important point: The idea of M. de Lesseps, that a sea-level canal, which has been so successful at Suez, is the final solution for Panama. A sea-level canal must be made and will be made at Panama. There will be a time when the importance of traffic will justify a passage of the highest class, that is, a sea-level canal. But is it justifiable to wait ten years longer in order to give the world the benefits of that great work? Is it not proper to take the intermediate solution, the lock canal? The lock canal should be

constructed now, for that assures an earlier completion of the long expected work. It will give a very satisfactory canal for a number of years. But the time will come when the character of the traffic will be so transformed that it will demand the transformation of the lock canal into a sea-level canal. This can be accomplished without stoppage of navigation, although it will cost much more to finish the canal while it is in operation than to make it prior to such operation. Mr. Bunau-Varilla.

From all standpoints, the speaker would justify the lock canal now; it will answer admirably the needs of navigation for a limited number of years—perhaps twenty or thirty—but thirty years will not pass before the absolute necessity of a sea-level canal will be seen, and plans for its transformation will be begun. Ten years' earlier opening justifies the less satisfactory form, to be in time transformed into its final shape, the American Bosphorus.

L. J. Le Conte, M. Am. Soc. C. E. (by letter).—The great problem to be solved, in any canal scheme, is the proper disposal of the storm-water discharges from the Chagres River water-shed. In the case of the tide-level canal—with one lock—the author's treatment of the subject seems to be stated fairly, and the final conclusions arrived at are based on well-established facts. There seems to be some room, however, for apprehension as to the probabilities of an endless source of contention with storm-water discharges coming in from both sides of the tide-level canal, and that these discharges into the canal would eventually give rise to vexatious delays and interruptions to traffic. This view of the question seems to be a strong one against the tide-level canal scheme. Mr. Le Conte

In the case of the high-level canal, the storm waters to be contended with are practically limited to those between Bohio and Obispo. As a final result there will be an enormous storage reservoir of fresh water, into and through which all traffic will have to pass. This artificial lake will furnish all the water needed for the summit level, with an active commerce, and, should future necessities call for it, an auxiliary dam and reservoir could be built at or near Alhajuela, which would meet all requirements.

As the author states, the high-level canal really makes two short canals and locks, combined with good anchorage ground and repair shops between. Vessels with foul bottoms could be readily cleared of troublesome marine growths before proceeding on their voyage beyond the canal. This is an important feature in favor of the high-level canal. The advisability of changing the location of the canal—around by Tiger Hill—and the substitution of 28-ft. for 42-ft. locks, suggested by the author, is certainly highly desirable from many points of view. The mere fact of the reduction in the lift from 42 to 28 ft. speaks for itself and needs no argument. Altogether, the proposed change in the location is to be commended.

Mr. Le Conte. The expediency of making an approach channel, of 200 ft., and 35 ft. deep at mean low water, on the Panama side, where the natural rise and fall of the tide is in the neighborhood of 20 ft., is an open question. The author proposes to make the depth available equal to 35 ft. at mean tide, which means 25 ft. at low tide. Of course, this would shut out all deep-draft vessels, for the time being, and turn over the canal traffic to the vessels of lighter draft. Perhaps this might do very well to expedite matters and push the enterprise along, but, sooner or later, it would become necessary to meet the demands of commerce by increasing this depth to 30 ft. at low water, at least, and quite possibly more will be demanded.

Mr. Morison. GEORGE S. MORISON, Past-President, Am. Soc. C. E. (by letter).—Replying to Mr. Meigs' first question, the Chagres is not unlike many rivers in the eastern and southern parts of the United States. It has about the same range between maximum and minimum discharges, and is subject to the same hydraulic laws. There is only one respect in which it differs from them essentially. The rainfall in the Chagres basin is double what it is on our rivers; the result is that the same maximum flood is obtained from an area of less than 900 sq. miles of drainage basin, which would come from four times this area in the United States. Twice as much rain must be disposed of; this means either a larger flood or a smaller basin; in the smaller basin the flood has less distance to travel. With one-quarter the area of drainage basin, we have one-half the aggregate rainfall with one-half the distance to run off, which means the same maximum discharge but a flood lasting but half as long.

The Chagres, under ordinary conditions, is a clear stream with a fall of from 2 to 4 ft. to the mile. In the upper river there are no signs of silt or other alluvial deposit, but between Alhajuela and Gamboa there is some small amount of bottom land and silt deposit. The erosion of this bottom land in times of flood is apparently the chief source of sediment in the lower river. With the high-level canal plan this silt region will be drowned and this erosion stopped. The amount of sediment which will be brought into Lake Bohio is less than must be expected in any of our Atlantic harbors. With the tide-level canal the danger will continue, but the amount of such erosion can hardly be considered excessive.

With reference to the difference between the elevation of the Chagres in flood times at Gamboa and the bottom of the proposed tide-level canal, anything approaching a vertical drop, if it were possible, would be destructive. Such a drop, however, is impossible. The bed of the Chagres is earth, not rock. If it were rock, this would be the place to build the upper dam. If ever a tide-level canal is built, the broad channel which will carry off the drainage of the Chagres must be extended at least a mile up the valley beyond the

canal, and such barriers must be constructed as will retard the flood in the river and thereby reduce its destructive force. No plan has ever been worked up in detail to meet this provision, the tide-level canal being removed from present consideration for the reasons given in the paper. Mr. Morison.

The estimates made in the paper are adapted from the estimates prepared by the Isthmian Canal Commission and used in reaching its conclusions. The principal savings are in the Bohio Dam, in the reduced amount of excavation in the Culebra Cut and the shallower portions of Lake Bohio, in the reduced excavation on the Pacific level, and dispensing with the diversion channels on the Chagres above Gatun, the Gatun Channel being retained. The cost of the canal itself from Colon to Lake Bohio is slightly increased, the Commission's estimate of the two being as follows:

	Commission's Plan.	Tiger Hill Line.
Atlantic Maritime Level	$19 006 199	$12 184 981
Tiger Hill Level	.....	5 638 874
" " Lock and Spillway	.....	5 024 056
Bohio Locks	11 567 345	9 014 632
	$30 573 544	$31 862 543

The increase of $1 290 000 is more than balanced by a saving of $2 700 000 in the cost of the diversion channels. By removing the canal to the more direct line, the present canal, which is now actually the bed of the Chagres, is left available as a diversion channel, a use to which it is admirably adapted.

There are four questions which the writer would like to have discussed at this time:

The first of these is the relative merit, under the circumstances, of the tide-level and the high-level canal, the difference of cost and time being as now estimated. The great difference is the time required for construction, which would be fully ten years longer for the tide-level than for the high-level canal. The tide-level canal could not be without locks. A 20-ft. tide on the Pacific side makes a tide lock necessary. The gates of this tide lock could stand open at certain stages of the tide, so that it would not absolutely limit the length of ships passing through, but with a tide-level canal, the same limiting sizes would exist for the greater part of each day as with a high-level canal. The tide-level canal would be a canal for the whole width of the Isthmus, although a portion of it would be pretty wide. The advantages of the inland lake would be lost. The inland lake makes two short canals with good anchorages and good repairing ground between —this is no small advantage.

The next question is whether it is important to try to reduce the size of the locks below the great lift proposed in the plans of the

Mr. Morison. Commission for the locks at Bohio. By using the third lock at Tiger Hill, as described in the paper, the normal lift of the locks is reduced from 42 to 28 ft. There is not the slightest doubt that a lock with a 42-ft. lift can be made and used, but an injury to such a lock in case of accident would be much more serious than to a smaller lock of less lift. Whether there is any more danger of injury occurring is a point which may be considered. Even with three locks, the time of passing through the eastern canal will be a little less than the time of passing through the western canal. Which is to be preferred, the two locks of 42-ft. lift or the three of 28-ft. lift?

The third question is the water supply for the summit level of the canal. The Chagres River supply is adequate for all but three months of the year. This deficiency can be obtained by drawing water from the lake. It can be obtained by another reservoir above Alhajuela. In the writer's judgment, it is best to postpone the final decision; to build the canal with no provision for this additional water, but, for the first few years it is operated, to allow the depth of water in the canal during the extreme dry season to be reduced, perhaps from 35 to 33 ft., and, ultimately, to provide a reservoir above Alhajuela to make good this deficiency. This would save something in the first cost of construction, and would ultimately give an indefinite supply. Is it right or wrong?

The fourth question is whether it is expedient, in a harbor like Panama Bay, with an extreme tide of 20 ft., to construct a channel giving a maximum depth at all stages of tide, at an additional cost of about $5 000 000. The reduction of this channel is one of the items which has reduced this estimate below the Commission's estimate. With a channel 35 ft. below mean tide, a ship requiring 25 ft. could always come in. A ship requiring 35 ft. could come in 18 hours out of the 24. How much is it worth while to pay for this additional 6 hours a day for ships of extreme draft? At high tide, with the channel as described in the paper, the depth would be 45 ft. With a channel 35 ft. deep below low water, it would be 55 ft. There are few harbors with large tides where anything like this has been done.

The question of lift of locks is one on which the writer feels more doubt than he does about any other point. The addition of the third lock means more gates and more possible risks; it increases the time of passage by the time necessary to pass through the additional lock. The additional risk is not serious, since the destruction of a gate in the Tiger Hill lock would not affect the water in the summit level, and the gate could readily be replaced. Furthermore, by keeping the lifts of the locks practically uniform throughout, the number of spare gates which must be kept on hand for repairs and renewals, would be reduced. The time required by the extra lock does not appear to be of material importance. The time required to pass through the

canal will be a matter of convenience of meeting points more than of close calculations of speed. As many vessels as possible will meet in Lake Bohio, and under any plan it will take longer to pass from Panama Bay to Lake Bohio than from Colon Harbor to Lake Bohio. Mr. Morison.

The total distance from the shore end of the enlargement for Colon Harbor to the shore end of the wide channel through the mud flats in Panama Bay is 41 or 42 miles. This is divided into two canals by a lake more than 12 miles long in the middle; 13 or 14 miles of canal navigation, not including locks, lie between Colon Harbor and the lake; a little more than 14 miles of canal navigation, not including locks, lie between Panama Bay and the lake. It is the navigation of these two canal sections which will regulate the passage across the Isthmus. While the speed of steamers through the canal will vary with their size, the time which a ship of mean dimensions would take to pass through these two sections may be estimated as follows, the speed in the canal being taken at five miles per hour:

Colon Harbor to Tiger Hill lock, 7.28 miles..	1 hour	27 minutes
Tiger Hill lock.....		45 "
Tiger Hill lock to Bohio locks, 5.73 miles...	1 "	9 "
Bohio double locks.....	1 "	15 "
	4 hours	36 minutes
Panama Bay to Miraflores lock, 4.15 miles..		50 minutes
Miraflores lock.....		45 "
Miraflores lock to Pedro Miguel locks, 1.34 miles		16 "
Pedro Miguel double locks.....	1 hour	15 "
Pedro Miguel locks to Lake Bohio, 8.84 miles.	1 "	46 "
	4 hours	52 minutes

This time could be reduced for smaller vessels; it will be exceeded by the largest vessels. It may be said, in a general way, that the time required to pass from either ocean into the interior lake will not be less than four hours, and it should not exceed five hours, except for the very largest class of ships. To these figures should be added the time required to pass through the lake and the time lost in Colon Harbor or Panama Bay. It would, perhaps, be fair to add an hour for each of these terminals, and 1½ hours for the passage of the lake; this would make the total time required for the passage of the canal from 10.5 to 12.5 hours.

Many steamers would take coal at Colon, and all would have to stop at the entrance port to pay tolls, take pilots, etc. There would be abundant room to tie up vessels in the broad harbor section at the Colon end. There is abundant anchorage in Panama Bay, the distance from the canal entrance to this anchorage being determined by the size of the ship and

Mr. Morison. other considerations. There is ample room for ships to anchor in Lake Bohio, where they could get fresh water, and, if necessary, make slight repairs. It is not probable that either section of canal would be traversed by night, except by the smallest class of vessels and in emergencies. Ships would prefer to enter the canal from either end about daylight or soon after noon. Ships entering in the morning would make a daylight passage, meeting in Lake Bohio. Ships entering after noon would spend the night in Lake Bohio and pass out on the following morning, proceeding under despatch orders and meeting the inbound ships at the locks. The Tiger Hill lock will be approximately half way between Colon and Lake Bohio, and the Pedro Miguel locks are approached in about the same length of time from the lake and from Panama Bay.

The intermediate level would reduce the seepage head between the lake and the level below the dam one-third, and increase the distance through which seepage must pass between the lake and the lower level of the Chagres at least three times. The estimated seepage would therefore be reduced one-third. The writer, however, considers that this question of seepage was covered in the discussion of the previous paper,* and does not believe that this reduction would be of sufficient advantage to have any important bearing on the main question. The saving of distance by the use of the Tiger Hill line is also of little value, but the saving of curvature is more important. The great advantage of this location, however, is that it keeps away from the low valley of the Chagres at places where the exposure is greatest. The small map, Fig. 6, shows in detail the present course of the Chagres, and the two swamps through which the overflow of the spillway must be taken if the old location is followed, and indicates the land which is less than 10 m., or 33 ft., above tide level. Below the dam the Chagres no longer follows its old bed, but for four miles runs through the canal, its old crooked course having been silted up, and from this four miles it must be excluded if the French location is adopted. If the lower location is adopted a channel must be cut through the ridge between the two swamps, and the canal must be protected by levees for at least five miles. This is undoubtedly practicable and can be made safe, but safety is always a measure of degree. The levees built for this purpose, which would be exposed to the wash of a flooded river, would be a more serious matter than the risk to the small embankments required to sustain the canal on the Tiger Hill location. The latter embankments would be exposed to no such wash, and the spoil from the canal would be enough to make them several hundred feet thick. Furthermore, the indications are that it would cost less to build the Tiger Hill line at tide level to the Bohio Locks than to complete and protect a canal on the original location. The writer, however, favors the intermediate lock.

* "The Bohio Dam." *Transactions*, Am. Soc. C. E., Vol. XLVIII, p. 235.

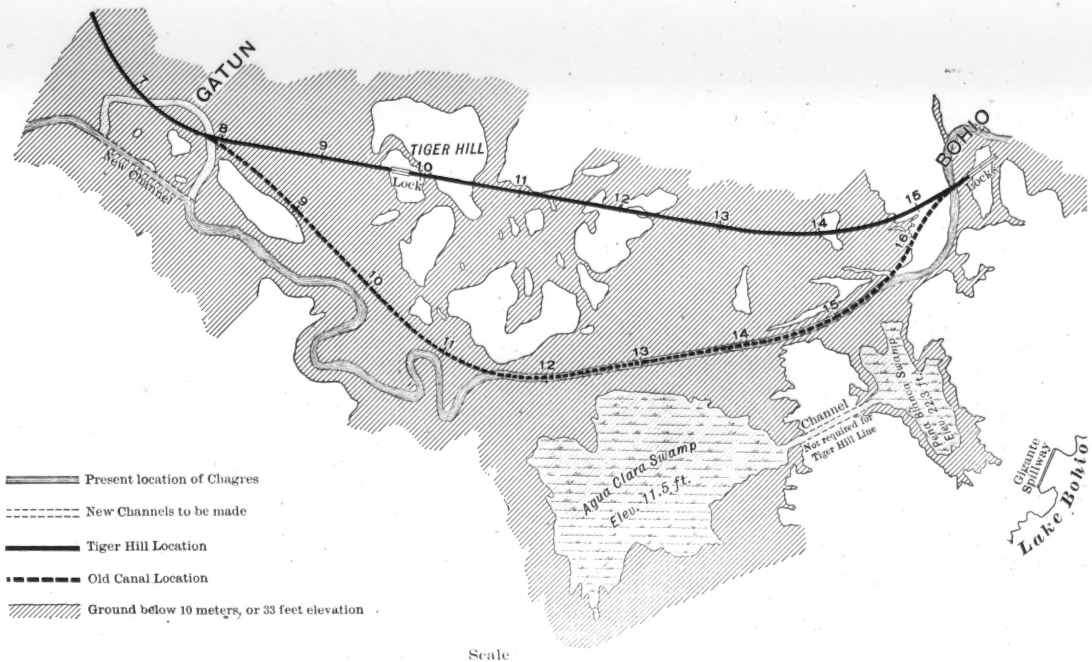

GATUN
TIGER HILL
Lock
BOHIO
Lock
New Channel
Present location of Chagres
New Channels to be made
Tiger Hill Location
Old Canal Location
Ground below 10 meters, or 33 feet elevation
Agua Clara Swamp
Elev. 11.5 ft.
Channel
Not required for Tiger Hill Line
Gigante Spillway
Lake Bohio
Scale
0
1
2
3 Miles

FIG. 6.

Mr. Morison. The proposition to raise the bottom of the canal through the Culebra Cut 3 ft., as described in the paper, would not necessarily affect the use of the canal for ships of the greatest draft. The depth of 35 ft. was selected to allow ships drawing 32 ft. to pass easily through it. If the precedent of the Manchester Ship Canal is followed, ships drawing 32 ft. could always be handled, although it would be hard to steer them. The writer, however, did not propose to reduce the depth through this summit level, but suggested that there were other methods of maintaining it, besides increasing the depth of this cut. The cost of the Alhajuela Dam will differ but little from the cost of this 3-ft. additional excavation, and will provide a much greater supply of water. If the construction of this dam is postponed until the completion of the canal, the cost of building a railroad to the dam site will be saved, as it can then be reached by water, and other economies, which attend the postponement of work until the rush is over, can be realized. It is not improbable that all the necessary water can be stored by the use of flash-boards, one of the cheapest devices ever made.

The principal objections raised to reducing the depth on the Pacific level relate to military rather than commercial conditions. It must be remembered, however, that the largest merchantmen of to-day are twice as big as the largest naval vessels, and that there are practically no naval vessels which draw over 30 ft. Furthermore, no fleet consists entirely of the heaviest class of ships, but every fleet contains a number of comparatively light-draft boats, used for despatch service and other purposes. If we assume that an entire fleet is taken through the canal at once, a very improbable supposition, the heavy-draft fighting ships will either precede or follow the light-draft ships, according as they expect to encounter a hostile fleet in front of or behind them. It would take approximately an hour to pass from deep water in Panama Bay to the Miraflores Lock. Assuming six hours as the length of time from mean tide to mean tide, this would leave five hours for the passage of the locks, which, allowing half an hour for each passage, special preparations being made, and using both locks, would enable 20 deep-draft fighting ships to pass from Panama Bay into the canal on a single tide. It is not probable that any such number of deep-draft ships will ever be concentrated in a single fleet.

It is the writer's opinion that the advantages offered by Lake Bohio as an interior lake which divides the transit into two short canals more than make up for the delays and limitations of the locks. The strongest argument in favor of the tide-level canal is the vulnerability of the locks. In time of war the canal might be closed entirely by a small guerrilla force. An accident, by which a heavy steamer carried away the gates of a lock, occurring near the beginning of the dry season,

might lead to the depletion of water in the lake to such an extent that navigation by deep-draft vessels would be impeded for several months. No such accident could occur to the single tide lock required for the tide-level canal. The danger from malicious destruction may be neglected, as the same harm could be done in various ways, although not as easily, in a tide-level canal. The gates must be kept safe by constant care, and undoubtedly some device can be made by which the discharge through the locks, when the gates are broken, can be stopped. Although the writer would prefer a tide-level canal when completed, he believes that it would be a serious mistake to undertake the tide-level plan at once. Mr. Morison.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 947.

A HIGH-VOLTAGE POWER TRANSMISSION.*

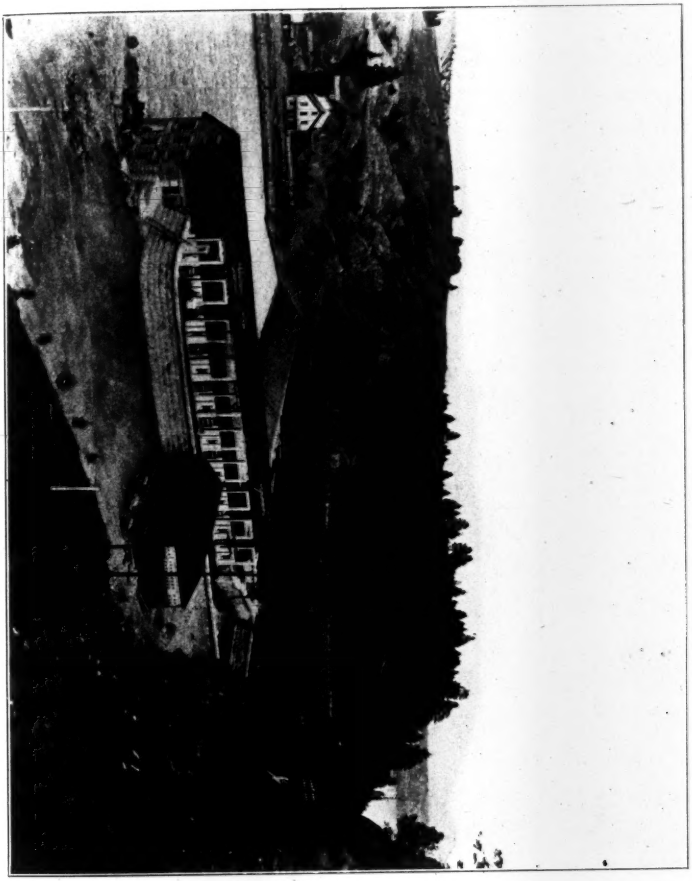
By M. H. Gerry, Jr., Assoc. M. Am. Soc. C. E.†

With Discussion by Messrs. F. O. Blackwell, P. H. Thomas, W. B. Potter, J. R. McKee and M. H. Gerry, Jr.

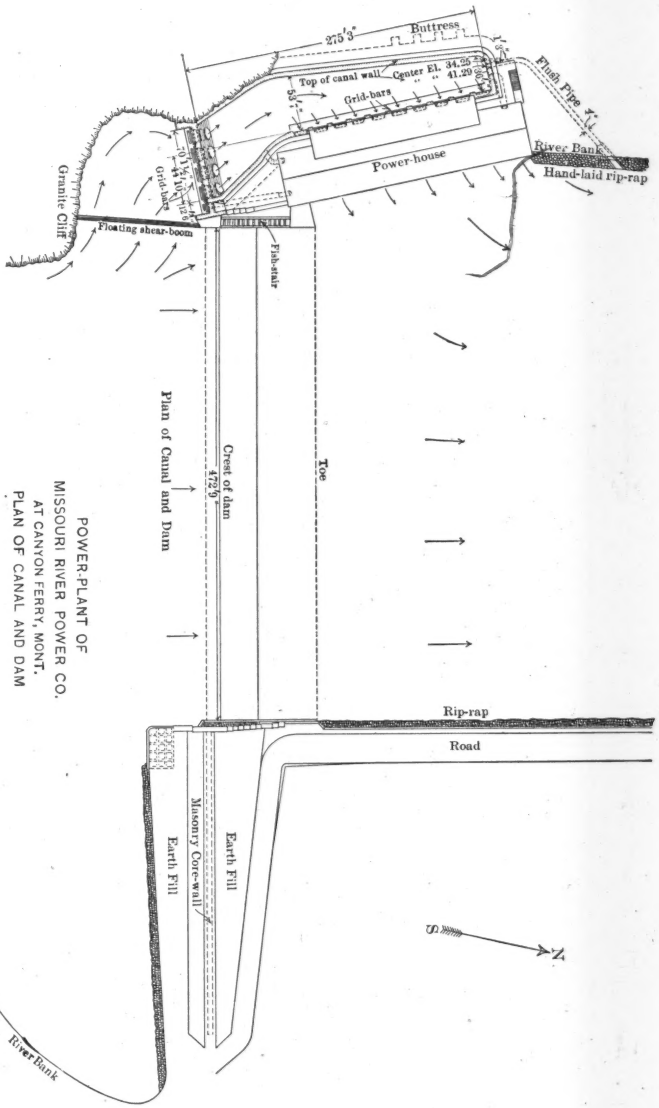
Introduction.

In 1891 the Missouri River Commission, United States War Department, completed a survey of the Upper Missouri River, including triangulation, topography, hydrography and check levels. The records of this survey for the first time made available complete engineering information regarding the Upper Missouri River. From Three Forks to a point below Canyon Ferry the field work was under the direction of G. A. Marr, M. Am. Soc. C. E., Assistant Engineer, and was fully reported by the Commission in 1891.‡ The river was then considered navigable to Three Forks, where the main stream is formed by the confluence of the Madison, Jefferson and Gallatin Rivers. From Three Forks to Canyon Ferry, the present location of the dam, the distance along the channel is about 81 miles. The watershed above Canyon Ferry is about 15 000 sq. miles in extent, comprising large parts of Madison, Beaverhead, Gallatin, Jefferson, Silver Bow, Lewis and Clarke, Meagher, and Broadwater Counties, of Montana, and the Yel-

* Presented at the meeting of March 4th, 1903.
† Elected Member December 3d, 1902.
‡ Annual Report of the Missouri River Commission, being Appendix AAA of the Annual Report of the Chief of Engineers, U. S. A., for 1891.



CANYON FERRY DAM, POWER-HOUSE AND CANAL.



POWER-PLANT OF MISSOURI RIVER POWER CO. AT CANYON FERRY, MONT. PLAN OF CANAL AND DAM

FIG. 1.

lowstone National Park. It is nearly all mountainous country, and embraces slopes of the Big Belt and main range of the Rocky Mountains, as well as a number of smaller ranges.

As the result of action by the Board of Trade of the City of Helena, an investigation was ordered by the United States War Department, and a report made on May 10th, 1892, by Captain Charles F. Powell, to the Chief of Engineers, United States Army, pointing out that no regular navigation existed above Great Falls, Montana, and stating that the construction of dams was feasible at a number of points on the Missouri River near Helena. An Act of Congress (approved July 13th, 1892) provided for a more extensive examination of the Missouri River from Three Forks to Canyon Ferry, with a view to determining at what points water-powers could be developed for manufacturing and other purposes. The examination thus authorized was made in 1893 by Mr. Edwin D. Vincent, Assistant Engineer, and the results of his investigation were reported by Captain H. F. Hodges, on January 22d, 1894, to the Chief of Engineers, United States Army. This report contained much valuable information, and indicated, especially, several practicable locations for dams.*

The Helena Water and Electric Power Company was organized, under the laws of the State of Montana, in May, 1896, and work was commenced on the dam at Canyon Ferry the following July, under the direction of Mr. Hugh L. Cooper, Resident Engineer, and J. T. Fanning, M. Am. Soc. C. E., Consulting Engineer. The original intention of the promoters of this enterprise was to supply electrical power and water for manufacturing, private and public purposes, to the City of Helena. About the time the work was begun, Mr. Barton Sewell became General Manager, and Mr. C. W. Whitley, Superintendent. A timber-crib dam, designed by Mr. Fanning, was completed in March, 1898, and the construction of a stone power-house to contain four units, together with the necessary penstocks, gates, etc., was well under way. It was at this time that the property came under the direction of the writer as chief engineer. The plant was completed on the original lines, and consisted of four generating units, each comprising a two-phase alternating-current generator of 750 kilowatts, directly connected to a pair of horizontal water-wheels.

* House of Representatives, Executive Document No. 96, 53d Congress, Second Session, Letter from the Secretary of War, transmitting Report of the Examination of the Missouri River from Three Forks to Canyon Ferry, Montana.

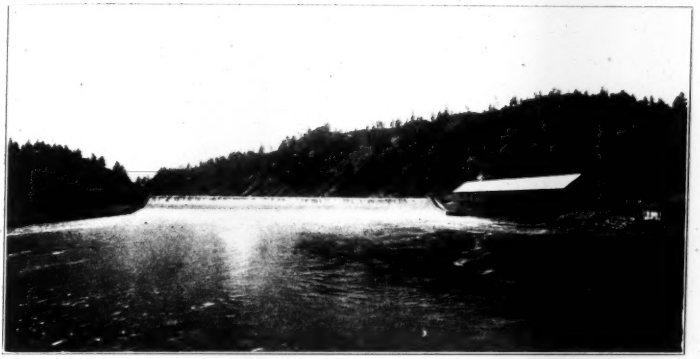


FIG. 1.—CANYON FERRY DAM AND POWER-HOUSE, LOOKING UP STREAM.

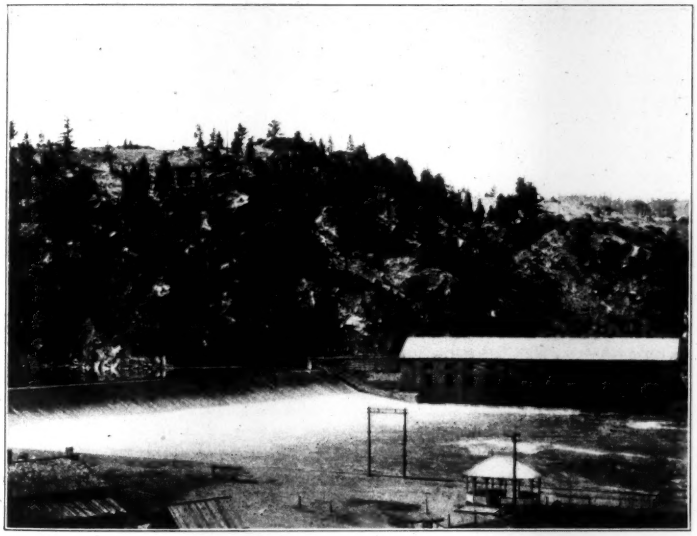
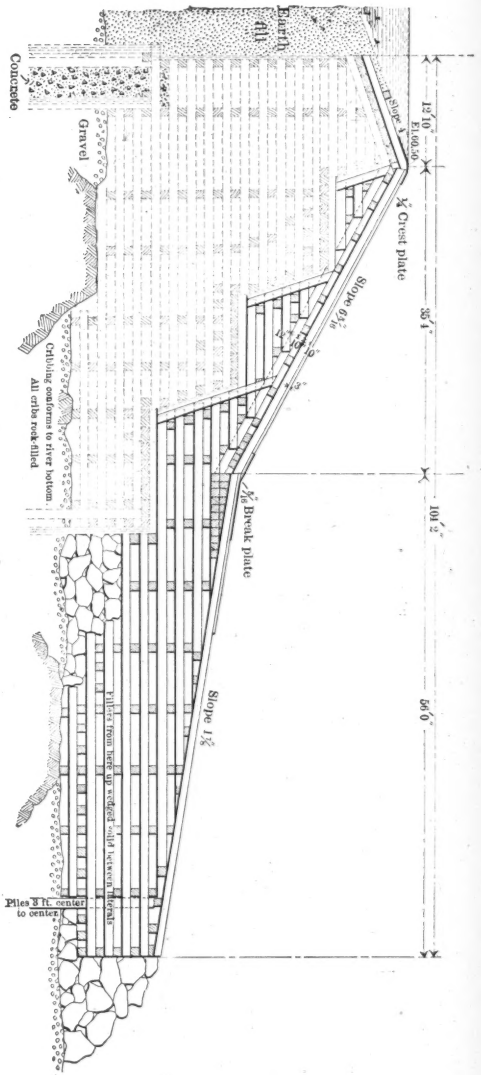


FIG. 2.—CANYON FERRY DAM AND POWER-HOUSE.



CANYON FERRY DAM
AS RECONSTRUCTED
FIG. 2.

Water was supplied to the wheels through two steel penstocks, 12 ft. in diameter, from a forebay excavated in the solid rock above the dam.

In May, 1898, shortly after the completion of the dam, and before the remainder of the plant was ready for service, the dam was damaged to some extent by extreme high water. It was immediately repaired and reconstructed on somewhat different lines, and since then has given no trouble. A complete electrical transmission system, operating at 12 000 volts, was installed, and a pole-line constructed to Helena by way of East Helena, together with several branch lines to near-by points. The plant went into regular service in October, 1898, supplying, from the first, three large customers: The East Helena Smelter (now the property of the American Smelting and Refining Company), the Peck Concentrating Plant (the property of the Helena and Livingston Smelting and Reduction Company), and the Helena Electric Lighting and Street Railway Company (now the property of the Helena Light and Traction Company).

The market for power at Helena and vicinity not being sufficient, it was decided in 1900 to enlarge the plant, and construct transmission lines to the City of Butte. To accomplish this result, the company was reorganized as the Missouri River Power Company, a New Jersey corporation, with the writer as Chief Engineer and General Manager. In connection with the enlargement of the plant, it was considered advisable to reconstruct and rearrange the entire plant, both in its hydraulic and electrical elements. In this paper a brief description of the various details of the reconstructed plant has been attempted; and it is thought that some interest may attach to certain of the hydraulic arrangements, and perhaps more especially to the electrical details of the 50 000-volt transmission system to Butte. It should be remembered that this plant was not designed originally for its present service, and that in its reconstruction many arrangements were necessary that would have been changed materially had an entirely new plant been built.

The Generating Plant.

The generating plant is located at the mouth of the Black Rock Cañon of the Missouri River, near the Canyon Ferry post-office, which is 17 miles from Helena and 65 miles from Butte. The works consist of an earth dam, with a masonry core-wall, located on the east side

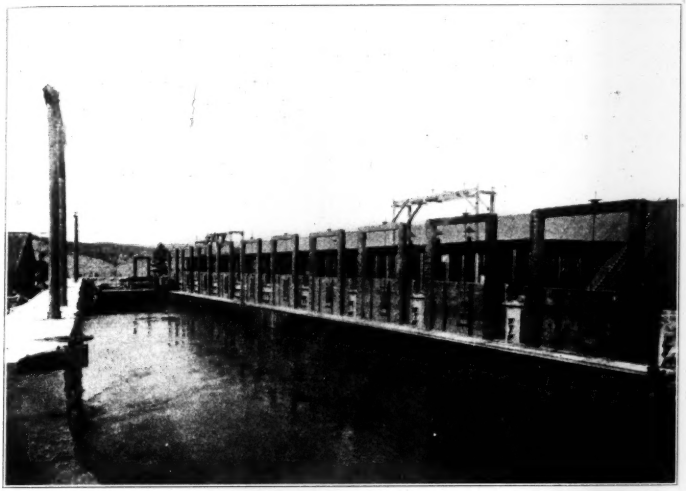


FIG. 1.—CANAL, HEAD GATES AND WEST SIDE OF CANYON FERRY POWER-HOUSE.

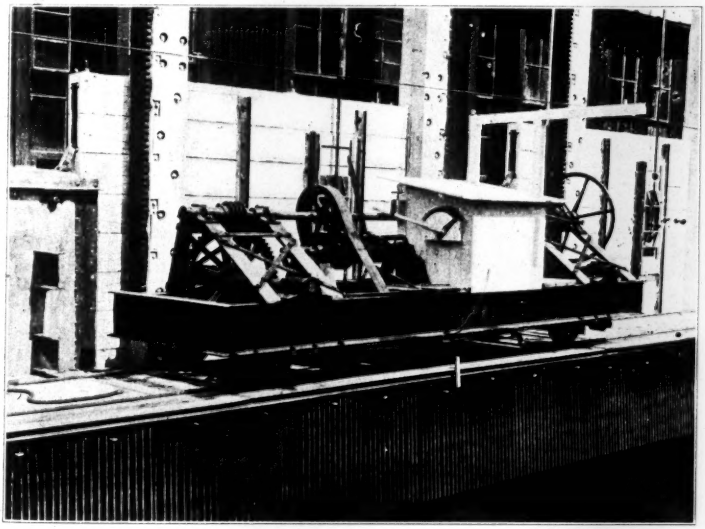
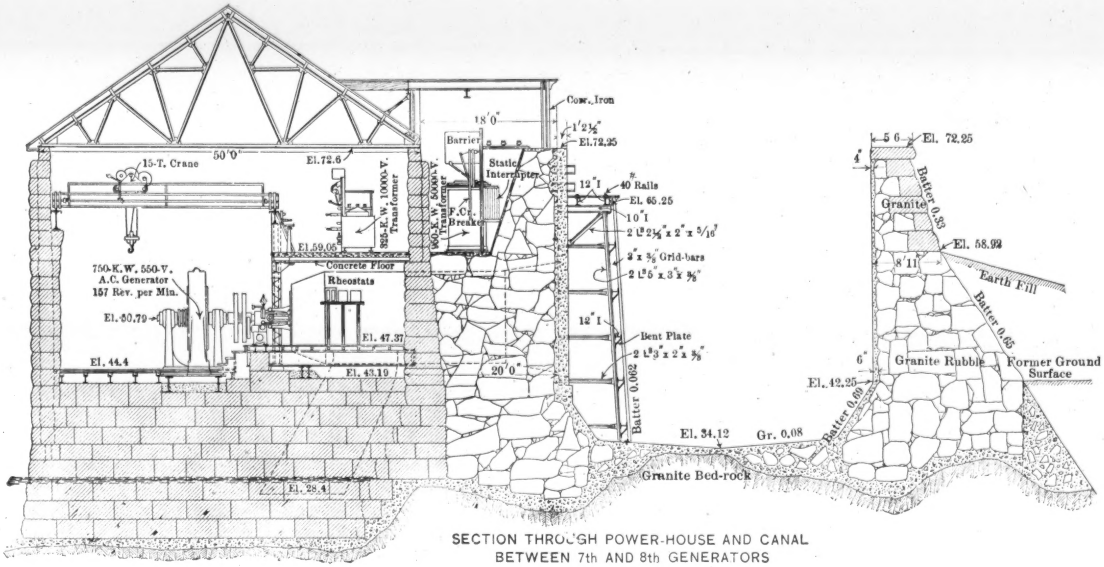


FIG. 2.—GATE-LIFTING CAR.



SECTION THROUGH POWER-HOUSE AND CANAL BETWEEN 7th AND 8th GENERATORS

FIG. 3.

of the river, a timber-crib dam, with masonry abutments, a masonry bulkhead having canal gates, a masonry canal, and a stone power-house. From the east bank to the abutment the distance is approximately 325 ft.; between the abutments is a clear spillway of 472 ft. 9 ins., and fish-stairs 12 ft. in width; and from the west abutment the masonry bulkhead extends 90 ft. to a nearly vertical granite cliff. The total distance from bank to bank on the line of the dam is approximately 900 ft.

Fig. 1 is a general plan of the works; Plate XV is a general view of the dam, power-house and canal; Fig. 2 is a section of the timber-crib dam, in its present condition, midway between abutments. The foundations of the power-house, canal walls and west abutment are on granite bed-rock, but in the middle of the stream the bed-rock is found only at exceedingly great depth, the cañon being in the nature of a fissure, or crack, in which the river has deposited silt and gravel. That part of the dam between abutments is a timber crib, rock-filled, and the drawing shows clearly its design, both before and after reconstruction. The dam forms a lake, or reservoir, 7 miles in length and more than 6 sq. miles in area. Fig. 1, Plate XVI, is a general view of the dam and power-house, looking up stream from the wagon bridge, which is about 800 ft. below. Fig. 2, Plate XVI, is a view from the east side of the river, and shows the power-house and the walls of the cañon.

The four pair of water-wheels received their water originally through two penstocks, but these were removed and a massive stone forebay, or canal, constructed. The dimensions of this canal are given in plan, in Fig. 1. Fig. 1, Plate XVII, is a general view of this canal, showing the water-wheel head-gates and the west side of the power-house. Fig. 2, Plate XVII, shows the canal, racks, gates and gate-lifting car. Fig. 3 is a sectional drawing through the canal and power-house, and Plate XVIII is a plan of the power-house and transformer-room. Figs. 5 and 6 are typical sections through the wall of the canal. The entire canal is of heavy, granite-rubble masonry, with the exception of a few courses on the outside of the wall, as shown. The canal is lined throughout, including the bottom, with Portland cement concrete.

The wheel-cases are of $\frac{5}{16}$-in. steel, 12 ft. in diameter, having conical bell-openings 14 ft. in diameter. These cases are set in the masonry, embedded in concrete.

PLAN OF POWER HOUSE

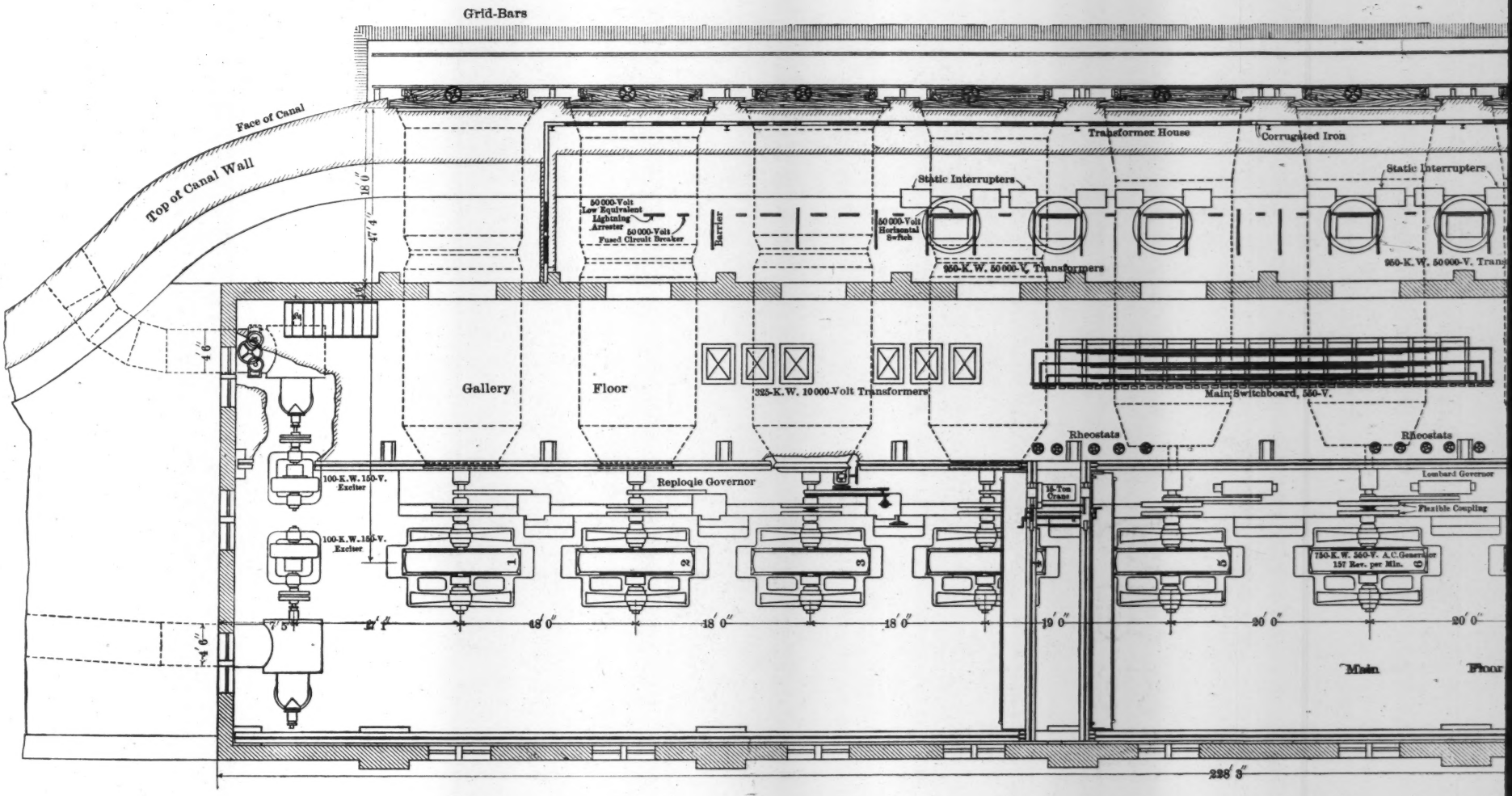


PLATE XVIII.
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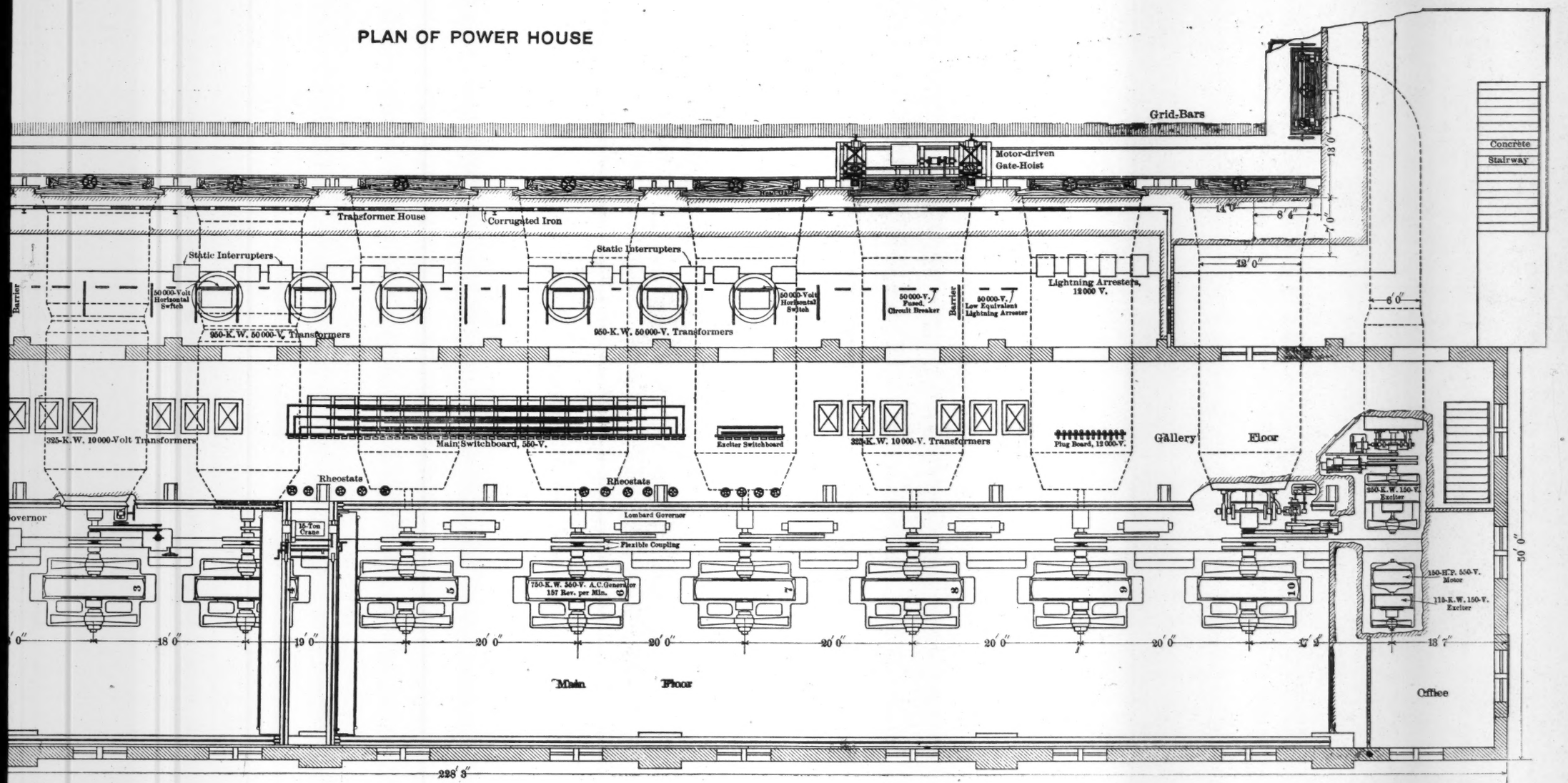
GERRY ON POWER TRANSMISSION.

PLAN OF POWER HOUSE



DETAILS OF GRID-BARS, GATES, SEALS, ETC.

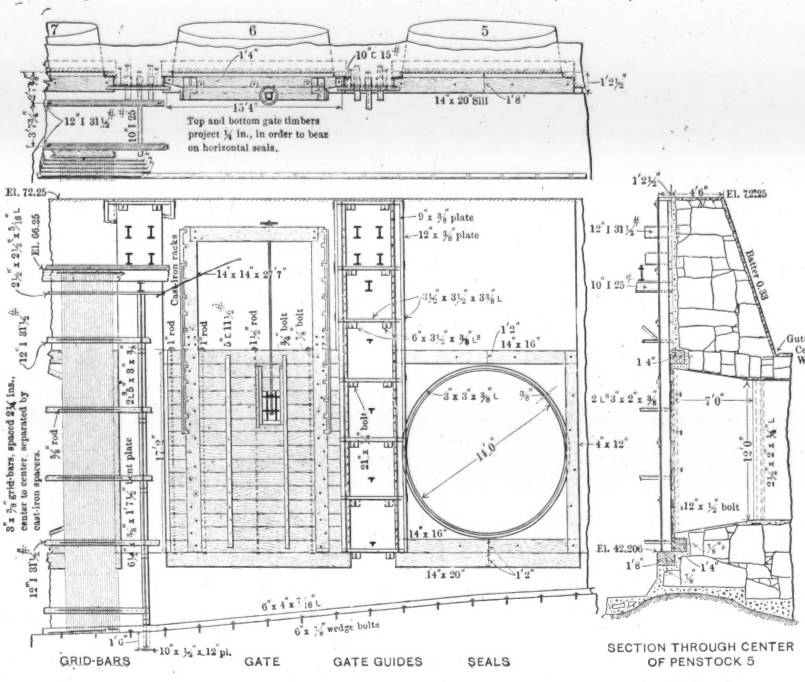
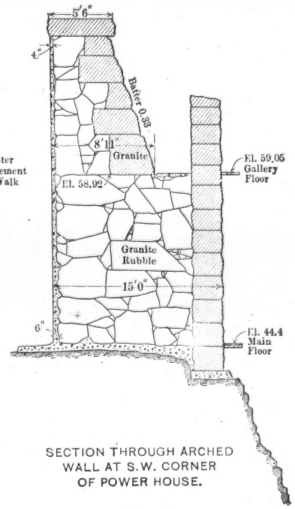


FIG. 4.

SECTION THROUGH CENTER OF PENSTOCK 5

FIG. 5.



SECTION THROUGH ARCHED WALL AT S.W. CORNER OF POWER HOUSE.

FIG. 6.

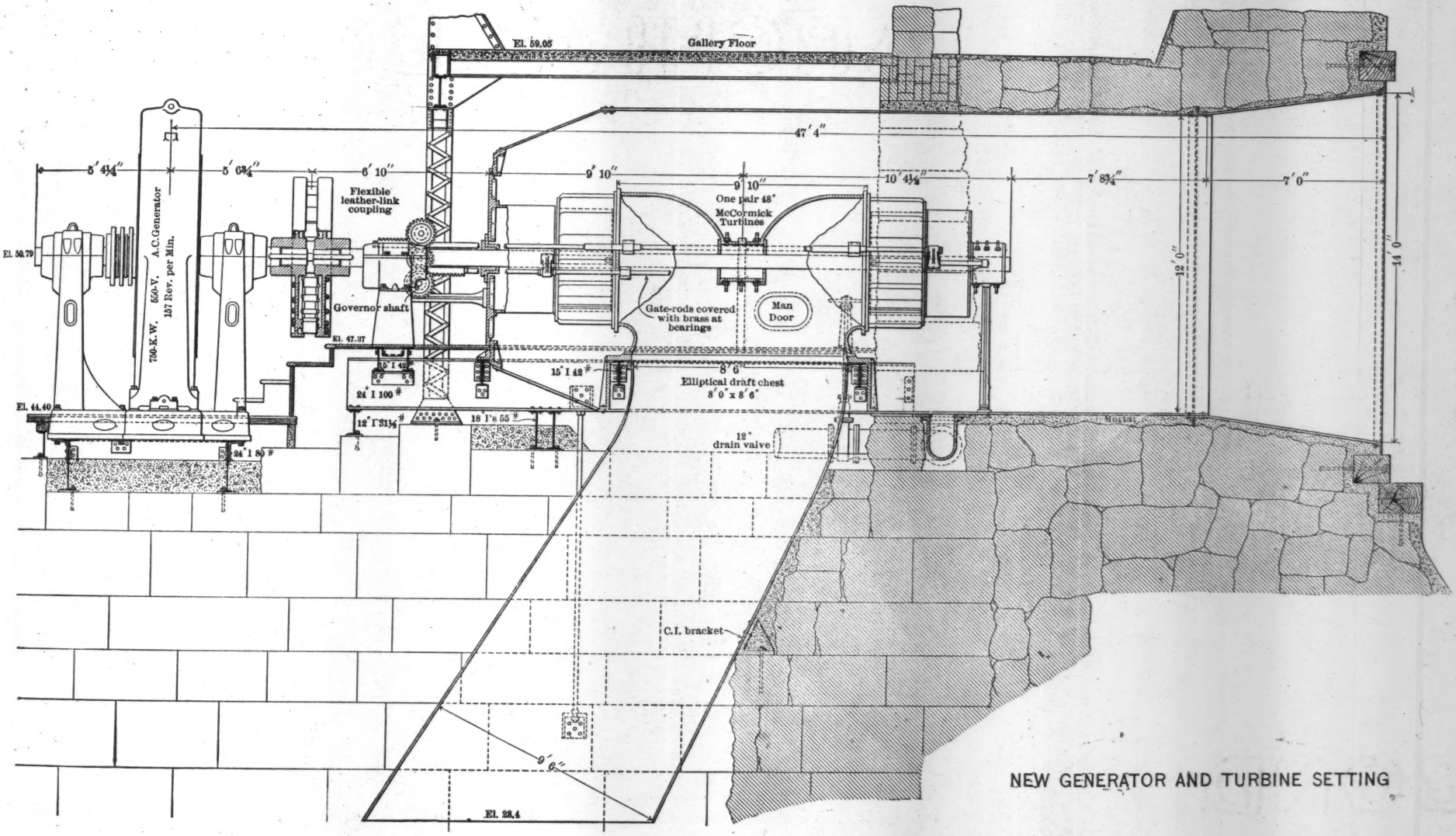
The main gates are ten in number, 15 ft. 4 ins. in width and 17 ft. 10 ins. in height, of Oregon fir, 16 ins. thick in the center. The gates slide in structural-steel guides built in the masonry.

The grid-bars are 3 x $\frac{5}{8}$-in. steel, spaced $2\frac{1}{2}$ ins. from center to center. They are supported by a structural-steel frame, which also carries the rails for the gate-operating car. The construction of the gates, guides, seals and grid-bars is shown clearly in Fig. 2, Plate XVII, and Figs. 3, 4, 5 and 6. The arrangement for operating the gates is shown in Figs. 7, 8, 9 and 10. This device consists essentially of a car, with the necessary mechanism, traveling on rails parallel to the east wall of the canal, in front of the gates. The rails on which the car travels support it only when moving between gates, or when moving its pinions into or out of mesh with the racks on the gate-lifting bars. The car receives its power, for all its movements and for operating the gates, from a 10-H.-P. direct-current motor, supplied with current from a trolley. The various motions of the car, and the lifting mechanism, are controlled by clutches operated by levers from a centrally located platform on the car. When the pinions are in mesh and the gates are being operated, the entire thrust is carried directly to the masonry, through 12-in. I-beams set in the wall, as shown in Figs. 8 and 9. The various details of the construction are shown clearly in the drawings referred to.

The power-house building is of granite masonry, 228 ft. 3 ins. in length and 50 ft. in width. A gallery, 18 ft. in width, extends the entire length of the building on the west side; and, at the same floor elevation as the gallery, located between the main power-house and the east wall of the canal, is a transformer-room 154 ft. in length. The general construction of the power-house is shown in Fig. 3 and in Plate XVIII. The building is entirely of masonry and steel, with the exception of the roof and main floor. The roof-trusses are of steel, and the roof is covered on the outside with corrugated iron. The gallery floor is of steel and concrete construction, and the walls of the house are in the natural stone. All the masonry, including the power-house, canal walls, abutments, and core-walls, is of gray granite, quarried and cut on the premises. Portland cement, of both American and European brands, was used throughout.

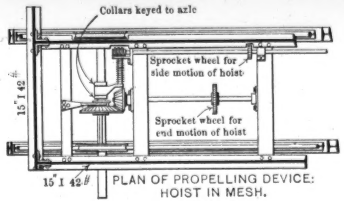
There are ten pair of water-wheels driving the main generators, two single wheels and one pair of smaller wheels driving the exciters.

PLATE XIX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. L, No. 947.
GERRY ON POWER TRANSMISSION.



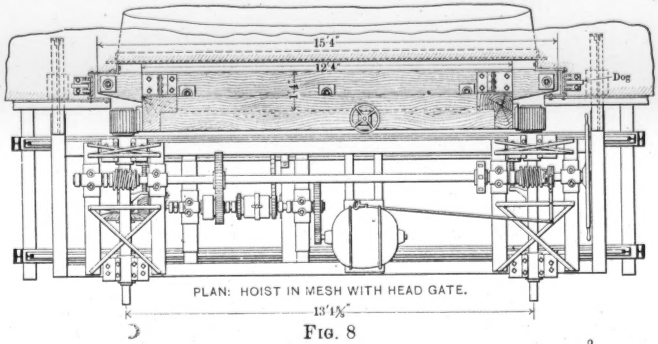
NEW GENERATOR AND TURBINE SETTING

ELECTRIC GATE-HOIST.



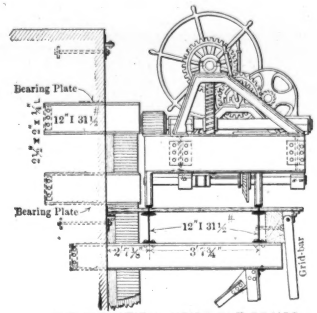
PLAN OF PROPELLING DEVICE: HOIST IN MESH.

FIG. 7



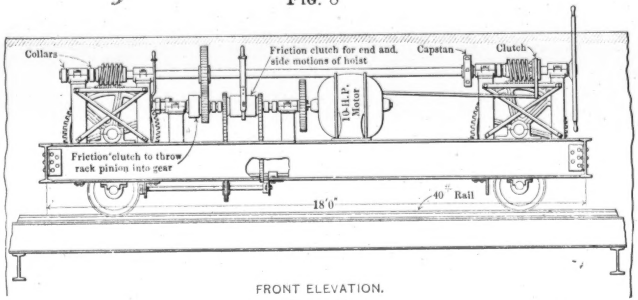
PLAN: HOIST IN MESH WITH HEAD GATE.

FIG. 8



END ELEVATION: HOIST OUT OF MESH.

FIG. 9



FRONT ELEVATION.

FIG. 10

The wheels in the old plant are of the "New American" type, and all the new wheels are of the "McCormick" type, manufactured by the S. Morgan Smith Company. Plate XIX shows a section through one of the new wheel settings. These wheels have 45-in. runners, and cylinder gates operated by draw-rods through the front head. Outside of the case, attached to the draw-rods, are racks which mesh with the gears operated by the governors. The wheels first discharge the water into central cast-iron draft-chests, then through elliptical draft-tubes into the tail-race. There are two water-bearings on each shaft, one at the outside of the wheel nearest the canal, and the other inside the draft-chest. A third bearing, of a ring-oiling type, is located entirely outside the wheel case and next to the generator coupling. This bearing is also designed to take the thrust in a direction parallel to the shaft, and for that purpose has on the shaft two solid projecting rings, which fit into grooves in the surface of the bearing. Fig. 1, Plate XX, shows the front head of No. 10 water-wheel, together with the governor and the generator. It also shows two of the exciters, one coupled to a pair of 24-in. McCormick water-wheels, and the other to an induction motor.

The governors in operation are of the "Lombard" type, and this apparatus is too well known to require description other than that the connections between the governors and the water-wheel gate mechanism are made through cut bevel and spur gearing.

The generators have revolving armatures, and are designed to deliver alternating current at three-phase, 60 cycles and 550 volts. The speed is 157 revolutions per minute. Each machine has a rated capacity, in electrical output, of 750 kilowatts at 80% power-factor. The four generators installed originally were two-phase, but they have been rebuilt and converted into three-phase machines. Fig. 11 is a general drawing of one of the new machines. The generators are excited separately by four 150-volt exciters, three of which are driven directly by water-wheels, and one by an induction motor, as previously stated. The connections between the generators and exciters and their water-wheels are made by means of flexible couplings, consisting of cast-iron discs united through rawhide drag-links. The generators and exciters are all of standard types, manufactured by the Westinghouse Electric and Manufacturing Company. A general view of the interior of the station is shown in Fig. 2, Plate XX, which also gives a good

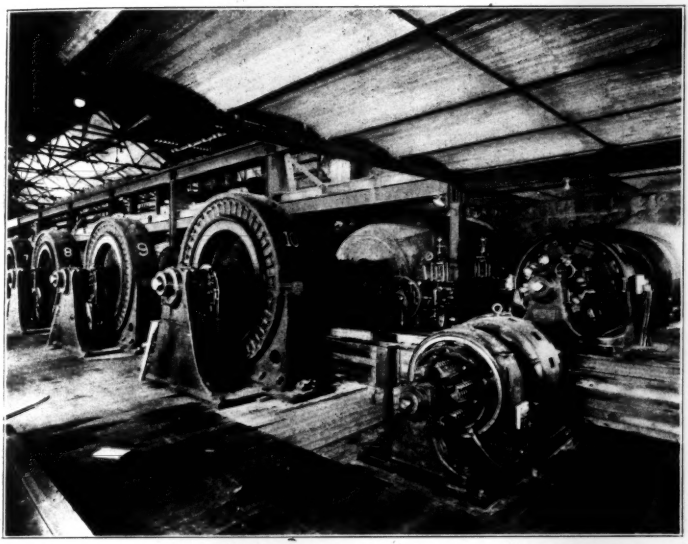


FIG. 1.—GENERATOR, WHEEL-CASE AND GOVERNOR.

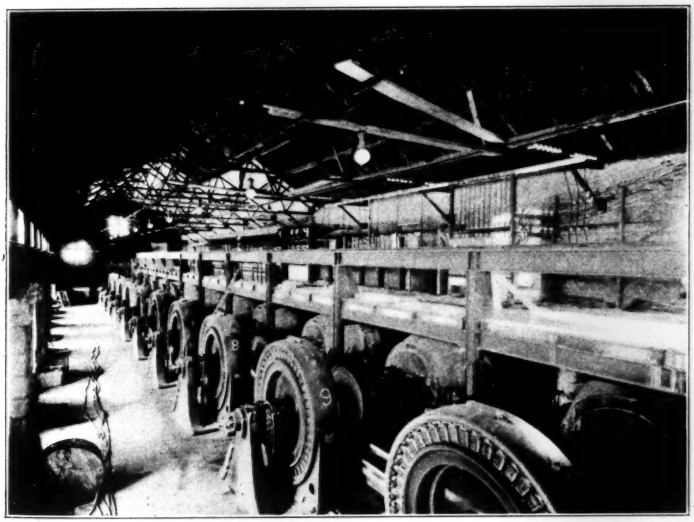


FIG. 2.—INTERIOR OF CANYON FERRY POWER-HOUSE.

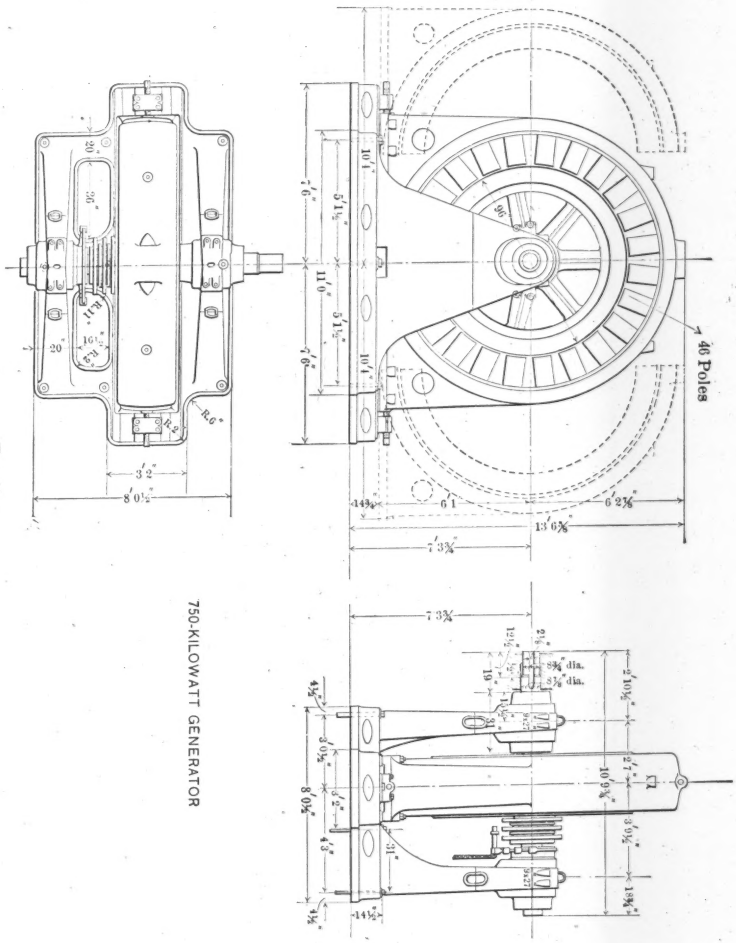


Fig. 11.

idea of the mechanical design of the generators and the arrangements in the station.

The switchboards, of blue Vermont marble, are located on the gallery floor in the center of the station. There are seventeen panels in the main board, four in the exciter-board, and four in the 12 000-volt plug-board. Fig. 12 is a general drawing of the main switchboard, and Fig. 1, Plate XXI, is a general view of the same board, as installed. The main board consists of ten generator panels, four feeder panels for the 12 000-volt service, two feeder panels for the 50 000-volt service, and one main junction panel in the middle of the board. There are three sets of main bus-bars, extending the entire length of the board, capable of being separated electrically in the middle by means of switches on the junction panel. In the arrangement of the board, starting at one end, are five generator panels, two feeder panels for the 12 000-volt service, one feeder panel for the 50 000-volt service, and the junction panel. On the other side of the junction panel the same number of feeder and generator panels is arranged in reverse order, so that all the feeder panels are grouped together in the center of the board, with the generator panels at the ends. By opening the switches on the junction panel, the board is divided electrically into two independent sections, either of which may be shut down for repairs while the other is in service. Each generator panel is provided with circuit-breakers, a polyphase wattmeter, an ammeter, and three sets of lever switches. Each feeder panel is provided with circuit-breakers, three ammeters, and three sets of lever switches. The junction panel has three sets of lever switches, and six polyphase wattmeters, one for each main circuit. The generator field switches and the integrating wattmeters for the feeders are mounted on small marble slabs, secured to the girder supporting the traveling crane, and are directly in front of the main board. The rheostats are mounted under the gallery floor, and are controlled by hand-wheels on pedestals, which are in front of their respective generator panels. Fig. 13 is a drawing of the exciter board, which is of the same general appearance as the main board. It has two separate sets of bus-bars, and each panel has circuit-breakers, a voltmeter, an ammeter and two sets of lever switches.

There are twelve transformers, of 330 kilowatts each, for the 12 000-volt service. These transformers are oil-insulated, air-cooled, and are

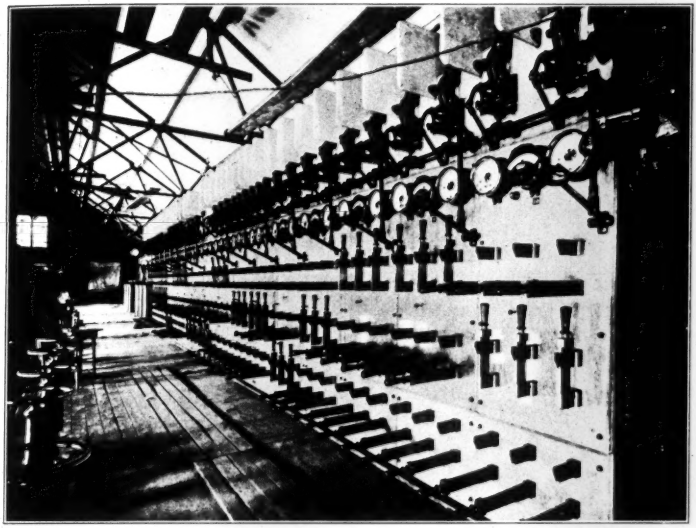


FIG. 1.—MAIN SWITCHBOARD, CANYON FERRY POWER-HOUSE.

FIG. 2.—POLE-LINES NEAR CANYON FERRY.

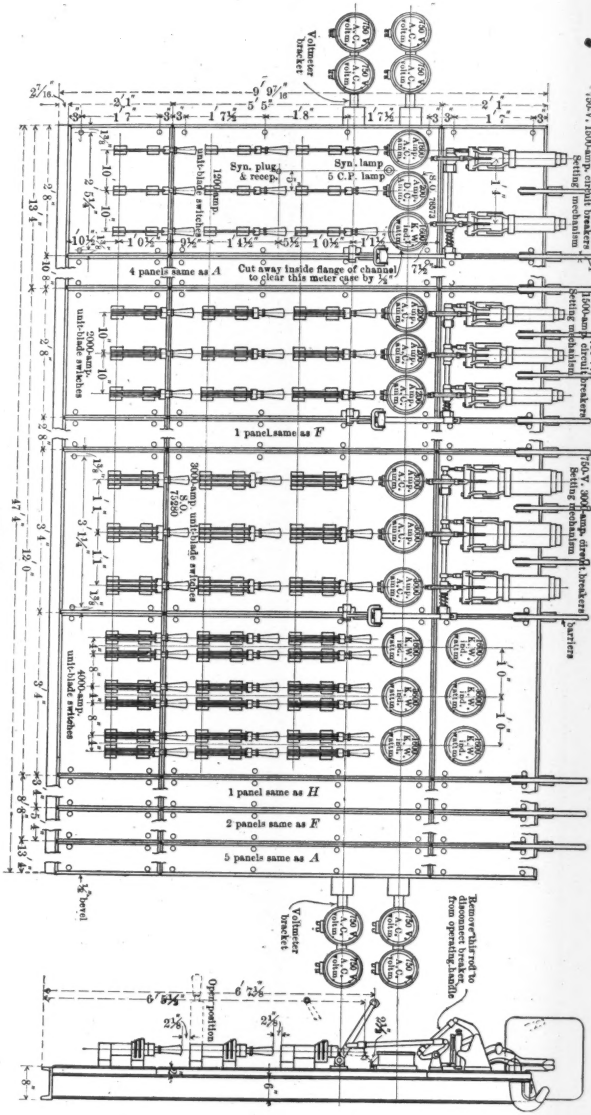

Voltmeter bracket
750 V. 1500-amp. circuit breakers
Setting mechanism
Syn. plug & recep.
Syn. lamp
5 C.P. lamp
1200-amp. unit-blade switches
4 panels same as A
Cut away inside flange of channel to clear this meter case by ½"
2000-amp. unit-blade switches
1 panel same as F
3000-amp. unit-blade switches
barriers
4000-amp. unit-blade switches
1 panel same as H
2 panels same as F
5 panels same as A
Remove this rod to disconnect breaker from operating handle
Open position
A B C D E F G H I J K L M N O P Q

FIG. 12.

arranged in four groups for three-phase delta connection. They are placed on the gallery floor, six transformers at each end of the switchboard. For the 50 000-volt service, there are six transformers of 950 kilowatts each. These transformers are oil-insulated, water-cooled, are arranged in two groups for delta connection, and are placed in the transformer-room between the wall of the power-house and the east wall of the canal. The 50 000-volt transformers are in heavy, boiler-iron tanks filled with a petroleum oil, and are cooled by means of brass pipes, immersed in the oil, through which circulates water from the canal. As the cooling coils are at an elevation which at times is above the water in the canal, the piping is arranged, by means of by-pass valves, so that the system can be filled and the water siphoned through the coils, discharging through draft-tubes extending below the level of the tail-race. A good head is secured by this arrangement, and the circulation of the cooling water is excellent. Gauges for measuring the flow of the cooling water, and thermometers for measuring the temperature of the oil and water, are on the transformers. Fig. 1, Plate XXII, is an end view of the 50 000-volt transformer-room, showing the transformers in position.

For the protection of the 12 000-volt service from lightning, standard type, "R," Wurts, lightning arresters are used. These consist of choke-coils and gaps, arranged so as to afford a multiple path to ground. As this apparatus is very well known, no detailed description need be given. For the protection of the 50 000-volt service from lightning, new apparatus has been designed. This consists essentially of two parts, the static interrupters and the lightning arresters proper. The static interrupters, so-called, consist of choke-coils and electrical condensers of small capacity. These coils and the condensers, immersed in a tank containing oil, constitute the static interrupters. Each lightning arrester contains 114 units of six gaps, about $\frac{1}{32}$ in. in width, and one large adjustable gap next to the line. The units are mounted on the face of marble panels, and around part of the units is shunted a resistance; and, in series with all the gaps, between line and ground, is a resistance. The connections of the static interrupters and lightning arresters are given diagramatically in Fig. 14. It will be seen that the choke-coils of the interrupter are connected in series with the transformer windings to be protected, and that the condenser is connected between the transformer terminal and the ground. The

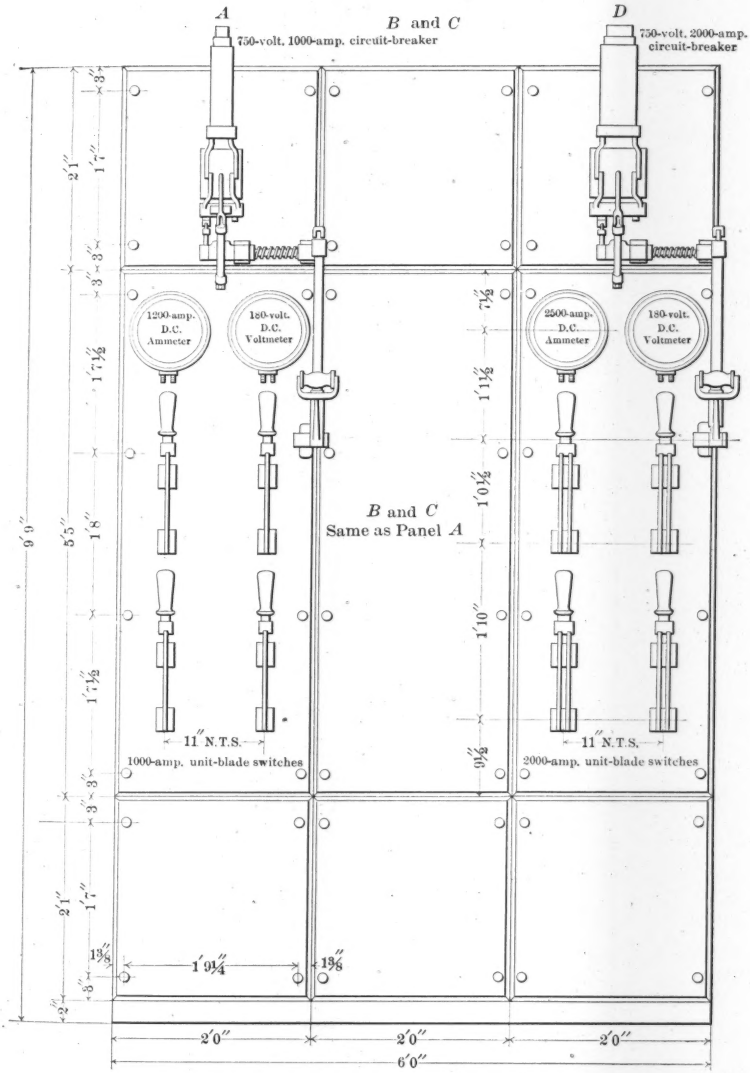

A
B and C
750-volt, 1000-amp. circuit-breaker
D
750-volt, 2000-amp. circuit-breaker
1200-amp. D.C. Ammeter
180-volt. D.C. Voltmeter
2500-amp. D.C. Ammeter
180-volt. D.C. Voltmeter
B and C
Same as Panel A
11″ N.T.S.
1000-amp. unit-blade switches
11″ N.T.S.
2000-amp. unit-blade switches
9′ 9″
5′ 5″
2′ 1″
1′ 7″
1′ 7½″
1′ 8″
1′ 7½″
2′ 1″
1′ 7″
3″
1′ 9¼″
1⅜″
2″
7½″
1′ 1½″
1′ 0½″
1′ 10″
9½″
2′ 0″
2′ 0″
2′ 0″
6′ 0″

FIG. 13.

function of the static interrupter is to receive the shock caused by the sudden application of a high potential to the terminals of the transformer, to reduce its abruptness, and to distribute the excessive electrical strain over such an element of time as to render it harmless in effect. The choke-coil and condenser act together, in this respect, the coil delaying the wave, and the condenser, by reason of its electrostatic capacity, absorbing part of the charge. The lightning arrester proper provides an available path to ground whenever the electrical strain becomes sufficiently excessive to break down the air in the gaps. The gaps with the series and shunt resistances are arranged so that when the excessive strain is removed, the power current, which often follows the discharge to ground, is broken.*

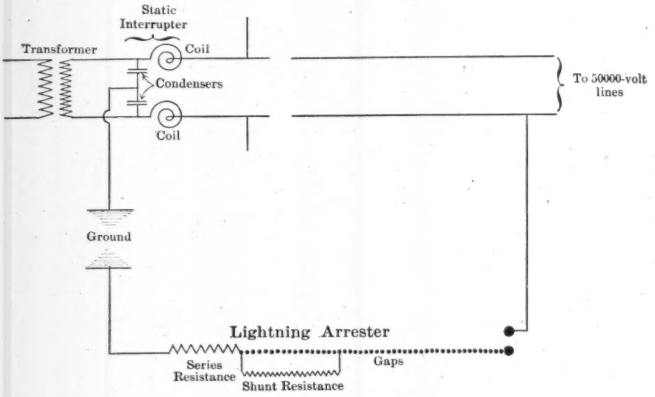


DIAGRAM OF CONNECTIONS OF STATIC INTERRUPTER AND LIGHTNING ARRESTER.

FIG. 14.

The arrangement of series resistance has been modified, on the arresters now in service, a fuse being shunted around this resistance so as to cut it out under ordinary operating conditions.

A complete diagram of the wiring of the station for both high and low tension is given in Fig. 15. The generators are wired directly

* A complete description of this apparatus may be found in a paper, by Percy H. Thomas, entitled "Static Strains in High-Potential Circuits, and the Protection of Apparatus," presented before the American Institute of Electrical Engineers, in February, 1902.

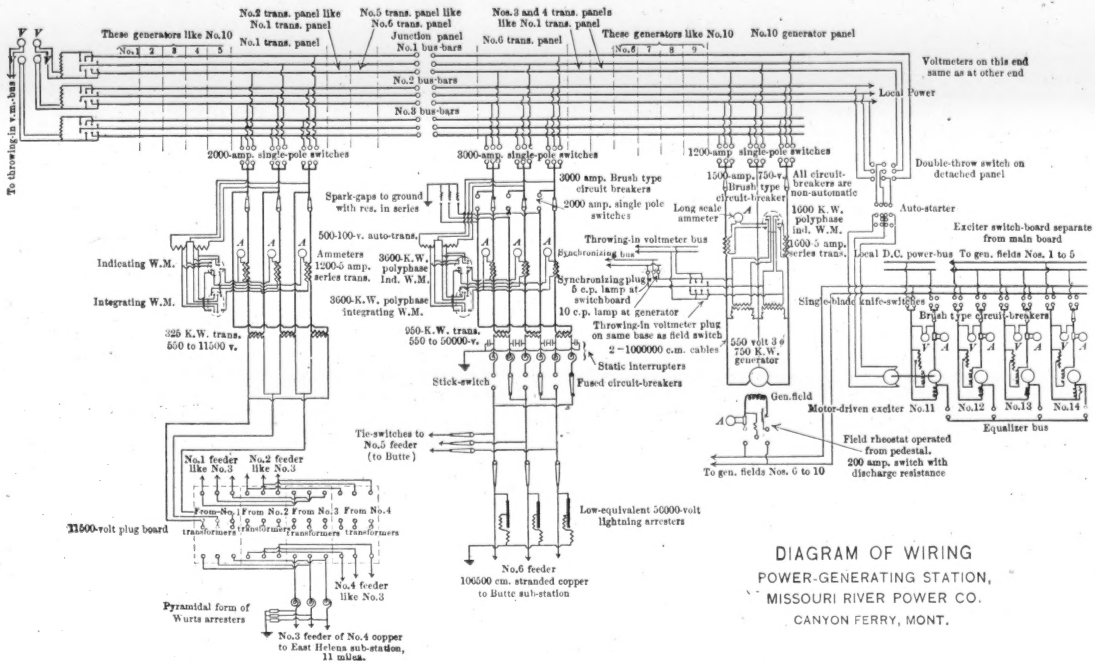


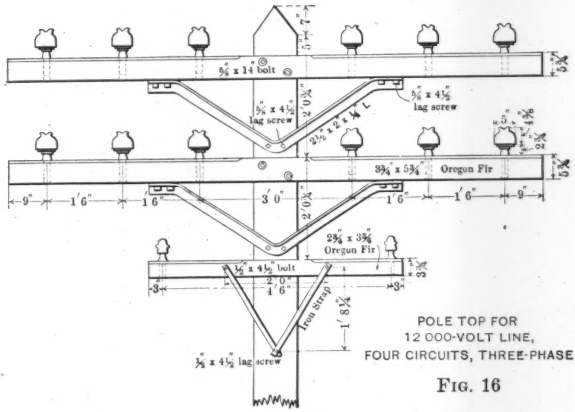
DIAGRAM OF WIRING
POWER-GENERATING STATION,
MISSOURI RIVER POWER CO.
CANYON FERRY, MONT.

FIG. 15.

to their respective panels on the switchboard. At the switchboard two of the legs of each generator circuit pass through circuit-breakers, and all three of the legs are connected with three sets of single-pole knife-switches. Each set of knife-switches, upon being closed, connects the three legs of each generator circuit with a set of bus-bars at the back of the switchboard. There are three sets of such bus-bars, and any generator may be connected with any one or all. After passing to the bus-bars the current is first conducted through the switches and the circuit-breakers on the feeder panels, then to the transformers. Especial attention is directed to the arrangement of the switches, circuit-breakers, and instruments, in this part of the wiring.

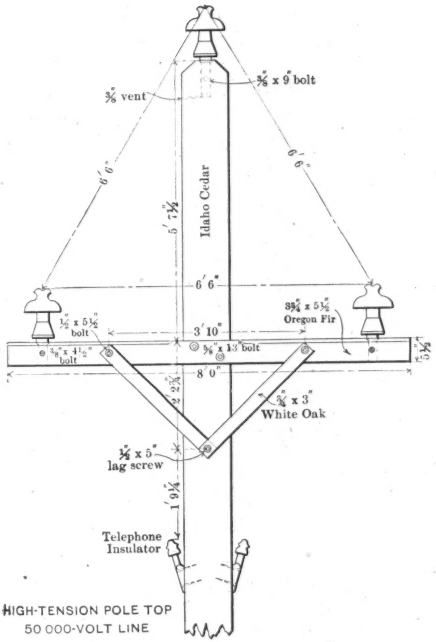
The current from the 12 000-volt transformers passes to the four-circuit plug-board, which is arranged so that any one of the four circuits may be connected with any one set of transformers, or any number of sets of transformers may be joined to any of the lines, either singly or in multiple. After leaving the plug-board, the 12 000-volt current passes through lightning arresters and then to the circuits extending to Helena and adjacent points.

From the six 50 000-volt transformers the current passes through static interrupters and high-tension switches, and is then united by a delta connection, after which it passes through a set of high-tension line-switches to the circuits extending to Butte. The lightning arresters, proper, are connected with each leg of these circuits just before leaving the building. Between the two 50 000-volt circuits are high-tension switches, arranged so that both sets of transformers may be operated together, either on one or both lines; or both lines may be operated from one set of transformers. The arrangement of switches, also, is such that any transformer may be put into or out of service at any time, without interfering with the operation of the plant. All the 50 000-volt main wiring is of 1 000 000 or 800 000-circular mil cable, insulated with rubber, and protected with a lead sheath. The 12 000-volt wiring is No. 4, solid copper, insulated with $\frac{5}{16}$-in. pure Para rubber, covered with double cotton braiding, and is supported on porcelain line-insulators. The 50 000-volt wiring is of No. 4 copper, having an insulation of $\frac{7}{16}$-in. pure Para rubber, protected with double cotton braiding, and is supported on the regular, glass, line-insulators and pins.



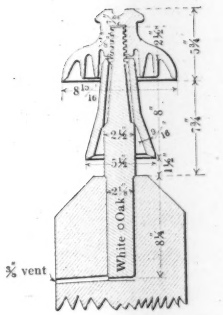
POLE TOP FOR
12 000-VOLT LINE,
FOUR CIRCUITS, THREE-PHASE

FIG. 16



HIGH-TENSION POLE TOP
50 000-VOLT LINE

FIG. 17



SECTION OF
50 000-VOLT
HIGH-TENSION INSULATOR,
SLEEVE, PIN, AND POLE TOP.

FIG. 18

The Transmission Lines.

There are three main pole-lines from the generating station: One carrying four power-circuits, each consisting of three No. 4, solid copper wires, and also a telephone circuit of two No. 10, copper wires. This line extends to the East Helena sub-station, where all the circuits pass through a four-panel plug-board, and lightning arresters of construction and arrangement similar to those on the same circuits at Canyon Ferry. Three circuits leave this sub-station, and, by means of the plug-board, any one or more of the four incoming circuits may be connected either with the sub-station lowering transformers, or with the three outgoing circuits, in any desired combination. After leaving the sub-station, the three circuits continue for about a mile on the same pole-line, and then branch—one circuit extending a distance of 5 miles to the Big Indian Mine, and the other extending 5 miles to the sub-station in Helena. The general design of the pole top, as arranged for the four 12 000-volt circuits leaving the generating station, is shown in Fig. 16.

The poles on the 12 000-volt lines are of Idaho cedar, the cross-arms of Oregon fir, the braces of angle iron, and the insulators of porcelain. The poles have from 9 to 12-in. tops, vary in length from 35 to 60 ft., when necessary to maintain the desired grade, are spaced at an average distance of 110 ft., and are set from 6 to 8 ft. in the ground. The main wires are not transposed, but the telephone wires are reversed in position at every third pole. The construction is heavy and rigid throughout, and has proved very satisfactory, as shown by the four years of unbroken service, almost without any expense for repairs.

The high voltage used on the Butte lines made necessary a special and somewhat novel construction. Each of the two pole-lines, from the Canyon Ferry generating plant to the Butte sub-station, carries three bare copper cables, arranged in a triangular position, 78 ins. apart. Each cable has an area of 106 000 circular mils, and is composed of seven strands. Fig. 17 shows the pole top, and Fig. 18 the insulator, sleeve and pin. Fig. 2, Plate XXI, is a view of the pole-line taken about one mile from Canyon Ferry, and Fig. 2, Plate XXII, shows a 50 000-volt insulator and sleeve assembled on pin.

The poles on the 50 000-volt lines are of Idaho cedar, the cross-arms of Oregon fir, the braces and pins of white oak, and the insu-

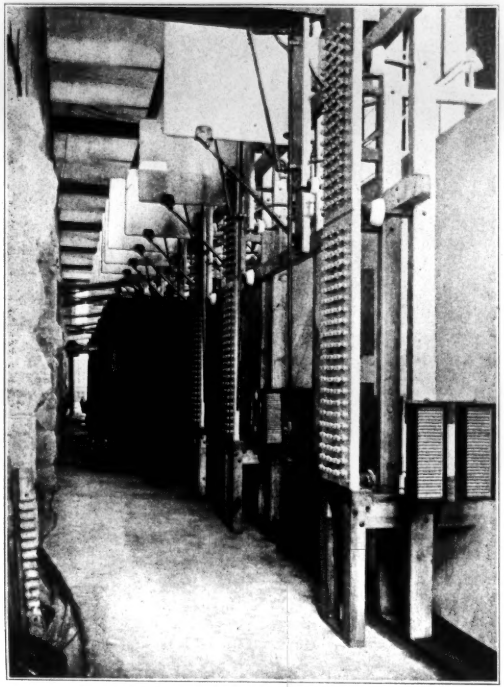


FIG. 1.—END VIEW OF 50 000-VOLT TRANSFORMER ROOM.

FIG. 2.—INSULATOR, SLEEVE AND PIN FOR 50 000 VOLTS, ASSEMBLED.

lators and sleeves of glass. The cross-arms, braces and pins are bolted together, the construction being very rigid. The pins in the top of the poles are of larger size and of greater length than those in the cross-arms, on account of the greater strains there present. The pins were prepared especially by being first dried and then boiled in paraffin until every vestige of moisture was removed. Wood prepared in this way will stand very great electrical strains, and the pins were tested frequently to 60 000 volts, without sign of failing.

The insulation of the circuits depends on the insulators, sleeves and pins, combined; the cross-arms and poles are not considered to have any part. The glass sleeves are not connected in any way with the insulators, and merely rest on a shoulder of the pins, as shown in Fig. 18. The object of the sleeves is to prevent the surface of the pins from becoming wet in a driving rain, thus carrying the ground potential above the level of the cross-arms. This function they perform admirably, but if the pins were not especially treated, so as to possess high insulating qualities, the sleeves would be useless. With metal pins, or even ordinary wooden pins, which for such high potentials are practically conductors, the absolute insulation, the air path to ground, and the electro-static capacity, are affected to such an extent that the efficiency of the combination, as a line-insulating device, is reduced materially. Each of the main circuits is transposed five times, making two complete turns between the power-station and the Butte sub-station. The telephone circuit, as shown in Fig. 17, is on one pole-line, only, and is composed of two No. 10, copper wires on double-petticoat pony-glass insulators. This circuit is transposed every fifteen poles. The switching arrangements at Canyon Ferry and at Butte are such that the power circuits can be operated either singly or in multiple. The two Butte lines are parallel, and are 50 ft. apart, where the nature of the ground will permit. The poles are from 35 to 75 ft. in length, the tops being from 8 to 12 ins. in diameter, and the butts from 12 to 24 ins. in diameter, according to the length. They are set from 6 to 8 ft. in the ground, and the standard spacing is 110 ft., with a maximum spacing of 150 ft., when required by the nature of the ground. The angle turned on any one pole does not exceed 20°, except by special construction. A survey of the entire route was made, including levels at each pole; a ground profile was prepared, and the grade line for the

top of the poles drawn in. For the greater part of the distance, a right-of-way, 200 ft. in width, was obtained by purchase or condemnation, but, at a few points, and in passing through towns, it was necessary to follow the public highways, and in some of the narrow cañons, where there were already two railroads, it became necessary to follow in part the railroad rights-of-way. All the timber and brush within 50 ft. of the poles on either side was cut, and all high timber at a greater distance, which in falling could possibly injure the line. The contours on the map, Fig. 19, give an excellent idea of the nature of the country through which the lines are constructed. Starting from Canyon Ferry at an elevation of 3 650 ft. above mean sea level, the Butte lines pass over three distinct summits and reach a maximum elevation of 7 300 ft. Much of the country is very rough and wild, and the section between Boulder and Woodville is practically without inhabitants. Through this section it was necessary to build wagon roads, in order to handle the material, and much of the right-of-way was cleared through heavy timber. In certain sections the grades average 500 ft. to the mile, and the transportation of the material was one of the serious problems.

The Sub-Stations and Secondary Distribution.

There are three sub-stations connected with the system, and at a few other points power is delivered directly from the 12 000-volt circuits.

The East Helena sub-station is operated at 12 000 volts. It contains oil-insulated and air-cooled transformers, also lightning arresters and plug-boards similar to those installed at the power-station, and already described. Practically the entire capacity of this sub-station is utilized by the East Helena Smelter for a great variety of purposes, all the power at the works being derived from this source.

The Helena sub-station is also on the 12 000-volt circuits. It contains high-tension apparatus similar to that at East Helena and at the power-station. From this point is supplied all the incandescent and arc lighting, and the street railway and other electrical power for the City of Helena. As the apparatus here installed has already been described, and as this sub-station, as well as that at East Helena,

Missouri R.
Canyon Ferry
Reservoir
Helena
East Helena
12000-Volt Pole Line
NOR. PAC. R. R.
Prickly Pear Cr.
50000-Volt Lines
Buffalo Cr.
Clancy
Jefferson
Boulder
North Fork
Little Boulder Park
Elk Park
Woodville
Butte
Substation
Anaconda Mine
N
S
MAP OF POLE LINES
Scale of Miles
0 2 4 6 8 10
Contours at 500 ft. intervals

FIG. 19.

represents only standard practice, no further detailed description is attempted.

The largest of the sub-stations is at Butte, having a transformer capacity of about 8 000 H.-P. The building is of steel and iron, with a brick floor and concrete foundations. The roof is lined with asbestos paper, held in position by wire netting. Fig. 20 is a plan of the building, showing the location of the principal apparatus. Fig. 1, Plate XXIII, is an exterior view of the transformer building, showing the method of entering the 50 000-volt lines. Fig. 2, Plate XXIII, is an interior view, showing the transformers, static interrupters, high-tension switches and wiring. Fig. 21 is a diagram of the wiring and connections of the apparatus. The 50 000-volt wiring is supported on glass line-insulators, and is of No. 4, solid copper, rubber-insulated wire, the same as that used in the generating station. The 2 200-volt secondary wiring from the transformers to the switchboard is of 800 000-circular mil cable, rubber-insulated, lead-covered, and laid in conduits under the floor. The 50 000-volt lightning arresters are duplicates of those in the generating stations, and are connected with each conductor immediately upon entering the building. After passing the lightning arresters, the main circuits pass through high-tension, fused circuit-breakers, then divide into a delta connection, inside of which is a pair of high-tension, fused circuit-breakers for each transformer, and also the static interrupters. Between the high-tension, line circuit-breakers and the branch of the delta connection, there are tapped, from each leg of the circuits, connections, through high-tension circuit-breakers, arranged so that the lines may be connected in multiple. All these connections are shown in the diagram.

There are six lowering transformers, of 950 kilowatts each, which are exact duplicates of those installed in the generating station, except that the coils of the low-tension side are connected in series, so as to give the electrical pressure of 2 200 volts instead of 550 volts. The six transformers are arranged in two groups, and on the 2 200-volt side are placed knife-switches and circuit-breakers, connected in the single-phase circuits inside of the delta connections. The three-phase connections are made at the main transformer panels of the 2 200-volt switchboard. There are two transformer panels, one for each group of transformers, and four main distributing panels. On each transformer panel is mounted a three-pole circuit-breaker, three ammeters,

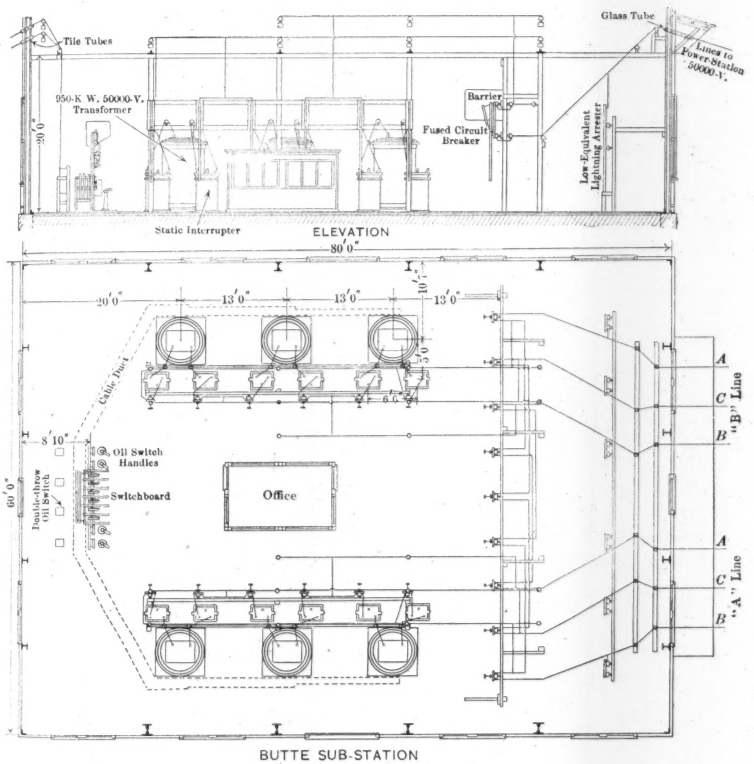

Glass Tube
Tile Tubes
Lines to Power-Station 50000-V.
950-K. W. 50000-V. Transformer
Barrier
Fused Circuit Breaker
Low-Equivalent Lightning Arrester
30'0"
Static Interrupter
ELEVATION
80'0"
20'0"
13'0"
13'0"
13'0"
10'-
5'0"
6'0"
Cable Duct
8'10"
Oil Switch Handles
Switchboard
Double-throw Oil Switch
Office
60'0"
A
C
B
"B" Line
A
C
B
"A" Line
BUTTE SUB-STATION

FIG. 20.

and six single-throw knife-switches. On each feeder panel is placed a polyphase wattmeter and three ammeters. In front of each feeder panel is a vertical switch-stand supporting an operating handle, controlling a three-pole, double-throw oil-switch, located back of the board. There are two sets of 2 200-volt bus-bars, and the knife-switches on the transformer panels are arranged so that either one or both sets of transformers may be connected with either set of bus-bars; or both sets of bus-bars may be connected with one set of transformers. Also, a single transformer may be cut out at any time, and the two remaining transformers supply current to the bus-bars. By means of the oil-switches referred to, the load can be transferred to either side of the bus-bars, or cut off entirely, without opening the transformer connections. After leaving the main-feeder oil-switches, the current again divides and passes through three-pole automatic oil-switches, one for each outgoing circuit. There are six of such circuits at present, and other circuits, with oil-switches, will be added as required.

The lightning protection on the 2 200-volt low-tension side of the transformers is provided for by the following arrangement: A lightning arrester having four $\frac{1}{16}$-in. gaps in series with a resistance, is connected, through a 5-ampere enclosed fuse, directly with one 2 200-volt terminal of each transformer. At the switchboard a similar lightning arrester is connected with each of the six bus-bars. On the feeder-circuits, just before leaving the building, a lightning arrester is connected with each leg, consisting of twelve $\frac{1}{32}$-in. gaps in series to ground, without fuse, but having a fuse and resistance shunted around six of the gaps.

There are three pole-lines carrying the six feeders from the substation to the points where the power is distributed; one line, carrying three feeders, extends a distance of $2\frac{1}{2}$ miles to the Butte Reduction Works, and, with two circuits, continues $\frac{1}{2}$ mile further to the Colorado Smelter. The second line, carrying two circuits, extends $1\frac{1}{2}$ miles over the Butte Hill, to the Anaconda Mines, where large air-compressing engines are operated, and whence radiate a number of lighter pole-lines, carrying circuits distributing power to most of the large mines in Butte. The third line extends about 2 000 ft. to the smelter and other properties of the Montana Ore Purchasing Company.

There are connected to the Butte circuits an unusual number of

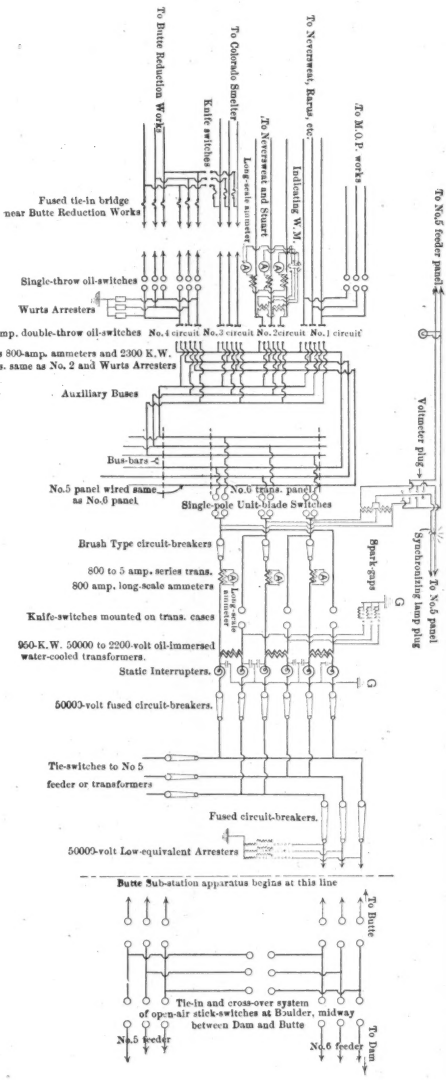


FIG. 21.

DIAGRAM OF WIRING,
BUTTE SUB STATION
MISSOURI RIVER POWER CO.

large motors, of 200, 300, 500, 600 and 800-H.-P. sizes, mostly of the induction type. Fig. 1, Plate XXIV, shows one of three induction motors of 300 H.-P. operating at the Colorado Smelter. Fig. 2, Plate XXIV, shows an 800-H.-P. induction motor of 175 revolutions per minute, used in driving an air compressor at the Anaconda Mines. This last-mentioned motor is believed to be the largest induction motor of such slow speed ever installed.

The Operation of the Plant.

In the operation of a transmission plant and system like that of the Missouri River Power Company, starting with a given plant and water supply, the desired result is the delivery, at distant points, of the greatest amount of electrical energy, in the most salable and satisfactory form, at the lowest possible cost.

For the generation of the power, a certain river flowage is available, varying with the seasons and the years. There is also available a large pond or reservoir which may be drawn upon to supply water in excess of the river flowage for short periods of time. The first important consideration is the nature of the load, whether variable or steady, and whether extending over a few hours or the entire day. The most convenient way of expressing this condition is by reference to the load factor, *i. e.*, the ratio of the average to the maximum load, expressed as a percentage, for the period of time over which the factor is determined. Integrating wattmeters furnish a ready means for determining with accuracy the average electrical power, and the maximum power can always be measured by various indicating or recording instruments. The load factors of several circuits supplying power for a variety of industrial purposes will usually differ widely, and the best result, as far as station loading is concerned, will be obtained by uniting all on one set of bus-bars, and operating the entire station as a unit. Sometimes this is impossible on account of different electrical pressures being demanded, or on account of certain circuits requiring greater refinement in regulation than others. The conditions at Canyon Ferry have been adjusted so that it is possible to operate all circuits together, so that the generating machinery is working at one load factor, or about 90% for the 24 hours; the load factors of the several circuits varying meanwhile among themselves from 95% on some to 10% on others. It is evident that the higher the load factor,

FIG. 1.—SUB-STATION AT BUTTE.

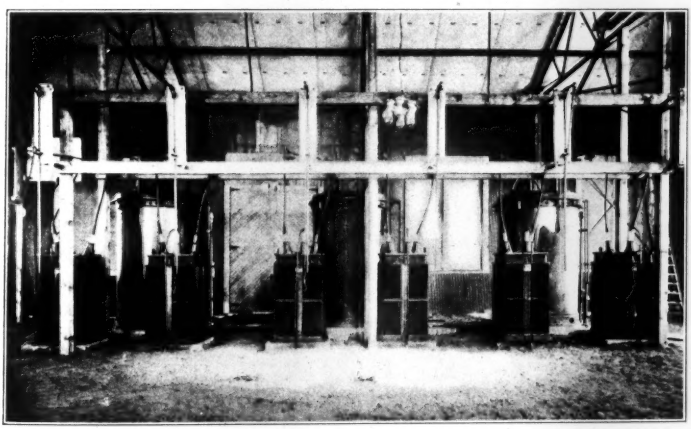


FIG. 2.—INTERIOR OF SUB-STATION AT BUTTE.

the smaller the machinery capacity required in service to carry a given average load; and it also follows, in general, that the efficiency is greater because the machinery can be operated more nearly at its full load.

The load factor also has an important bearing upon the speed regulation of the water-wheels, and upon the electrical regulation of the system. Commercial considerations frequently require the acceptance from a customer of a power load of low factor, but it is the best practice to regulate the design so that such loads can be combined with others, resulting in an average condition more favorable to economical operation. It is the practice of the Missouri River Power Company to operate the entire station as a unit, connected in multiple, but the design is such that circuits can be operated separately under special conditions, or in emergencies of any kind. The station load factor being determined, the amount of average power which can be generated will depend upon the flow of the river, provided there is a pond or reservoir affording water storage sufficient to permit the carrying of the peak loads, without seriously affecting the head. This is a most important matter, as it permits the plant to carry an average load fully up to the flowage of the river, while, without such a reservoir, the power generated could not exceed the maximum at the station, which would be materially less than the average. At Canyon Ferry the pond is ample for this purpose.

Next in importance to the form and amount of loading on the station is the question of speed regulation. For many years close speed regulation was thought impossible for water-wheels driving machinery subject to suddenly varying loads; but the difficulties have been overcome, and it has been found that very satisfactory results can be obtained by correct designing, and the use of proper governors to actuate the water-wheel gates. The first consideration is to have such hydraulic design that the water can pass freely to the wheels, and to avoid those arrangements which require a considerable change in the velocity of a long column of water, under a relatively small head, with varying gate on the wheels; such, for example, as long penstocks having little hydraulic grade. If the design in this particular is bad, the regulation will suffer, regardless of the excellence of the governor, as a time element will be introduced in which the water column will be accelerated or retarded, and during

which the water-wheels cannot fully respond to the gate opening, on account of the varying effective head. One of the principal reasons leading to the removal of the old penstocks and the construction of the open canal at Canyon Ferry was to obtain better design in this particular, resulting in better speed regulation for the plant. The nearer the design approaches to an absolutely open setting, with the head entirely above the wheels, the better the regulation. From an inspection of the drawings it will be seen that the water passages from the canal to the wheels are very direct, and that the design approaches closely to the most desirable conditions. Next in importance, after proper hydraulic design, is a good governor, having ample power, and proper arrangements for relaying and returning the speed to normal at all points of the gates. It is also essential that the governors have a distinct speed characteristic, in order that the various wheels driving generators connected electrically in multiple may divide the load properly at all points of gate. If the governors do not have such a speed characteristic, the conditions will be unstable, and the wheels will shift the load among themselves, some taking more than others. The governor used in this plant is well known, and possesses the requirements mentioned. Besides a good governor, it is necessary to have a water-wheel with gates designed for easy control by the governor mechanism. Builders of water-wheels have given this subject considerable study, and great improvements in design have been made in this particular. The essential requirements are that the gates move easily at all points, and possess little inertia. The cylinder and wicket types of gate alone seem to meet these requirements for low-head turbine wheels without seriously sacrificing efficiency. The new wheels at Canyon Ferry have cylinder gates, and the speed regulation does not exceed 3% under severe changes of load, and 2% under ordinary working conditions.

Of the operating electrical features, that of most general interest is the high voltage on the Butte transmission circuits. The electrical pressure is maintained regularly at 50 000 volts and more. This is a pressure higher than is used in regular commercial service elsewhere at the present time, within the knowledge of the writer. For many months a regular commercial service has been maintained at this pressure, and the results have been very satisfactory. Lightning, wind, rain and snow have not interfered with the regularity of the

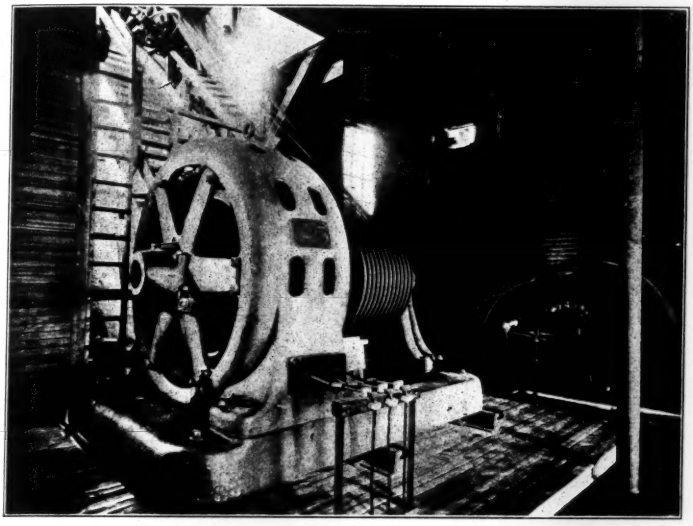


FIG. 1.—A 300 H.-P. INDUCTION MOTOR IN COLORADO SMELTER.

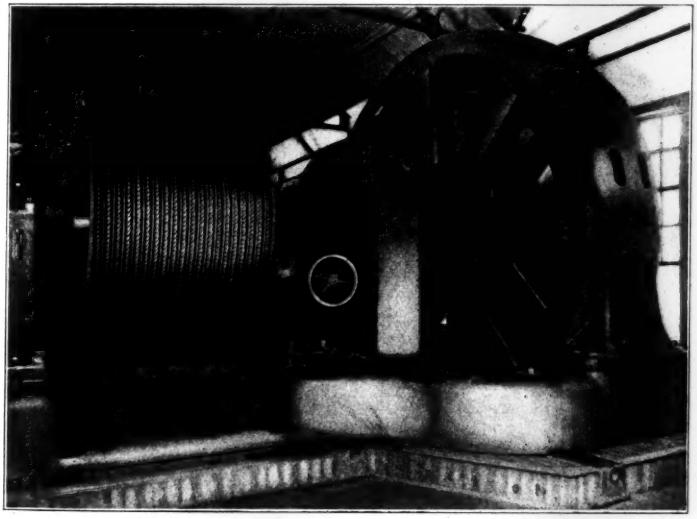


FIG. 2.—AN 800 H.-P. INDUCTION MOTOR AT ANACONDA MINE.

service. The electrical losses due to the pressure are trifling in amount and far less than the gain in other respects from the same cause. The behavior of these circuits does not differ greatly from similar circuits at lower voltages, and there are no luminous effects, or discharges, on the lines, under normal working conditions. A very satisfactory telephone service is maintained on one of the high-tension pole-lines.

The two transmission lines to Butte are generally worked in multiple, but each line has ample capacity for carrying the entire load, when necessary. In the operation of the plant it is customary to energize the lines separately from the station, and to synchronize and tie the lines together at the Butte sub-station. The overload switches and other special devices, already described, provide ready means for disconnecting any line or feeder, and any single unit or group of units of apparatus, either at the power-station or at the sub-station, can be put into service or instantly removed therefrom without affecting the service, or without the knowledge of the customers that anything has taken place.

The regulation of the electrical pressure is one of the most important factors in the successful operation of a transmission system. The maintenance of practically constant speed is, of course, a requisite. The generators should have good inherent electrical regulation, not only for changing load, but more especially for varying power factor. The electrical regulation of the transformers is of importance, but more especially is that of the transmission lines and feeders. The inductance, capacity and resistance of the transmission circuits can be controlled in design to a certain extent, and, if the nature and amount of loading are known in advance, the line regulation can be predetermined with accuracy. The nature of the load, especially as to its power factor, has a most essential bearing on the regulation. By uniting the various loads and working the entire system as a unit, there is obtained, under ordinary conditions at Canyon Ferry, a station power factor of about 90 per cent. The regulation at the Butte sub-station is within 5% of normal, under regular service conditions. The problems of electrical design and operation involved in this subject are complex, and are not within the scope of this paper, hence are not here treated mathematically or in detail.

At the generating station, the usual operations of starting, stop-

ping, switching, paralleling and synchronizing are those common to all large power plants, and do not merit special description.

The writer desires to acknowledge the valuable services rendered, both in designing and construction, by his able assistants: James C. McKitrick, C. E., in charge of the general construction at Canyon Ferry; A. C. Pratt, E. E., in charge of the power-station machinery and electrical construction; Wm. L. Miller, E. E., in charge of the sub-station and all construction in the City of Butte; and Mr. E. E. Davis, in charge of all transmission-line construction.

DISCUSSION.

F. O. Blackwell, Esq.—There are some features of electric power transmission which may be of interest. The first is that it is practically independent of distance. If a potential is used which is proportional to the distance, any distance can be reached. It does not matter much whether the power is carried across the room, or whether it is carried 100 miles—the same quantity of copper per horse-power is required for the same efficiency. Mr. Blackwell.

Having this independence of distance, the generation of power can be concentrated from several different places in one power-plant, for instance, from Helena and Butte, as has been done in this particular instance. The reverse can also be done; that is, the power can be brought from many different points and delivered to one place to be used.

Butte is also a good example of this. They have, at a water-fall near Butte, three electric power transmission plants, in addition to a 3 000 H.-P. steam-driven electric plant in the City of Butte. They bring 5 000 H.-P. 60 miles from the Missouri River, 2 000 H.-P. 67 miles from the Madison River, and 2 000 H.-P. 20 miles from the Big Hole River, into the city. Three of the plants are working together, as if the generators were all in the same building, notwithstanding their great distance apart.

In some parts of the country they have as many as seven or eight steam- and water-power electric stations, perhaps 50 or 100 miles apart, all feeding into the same distribution system and working in unison like one plant. Power, to-day, is being delivered commercially to San Francisco and the neighboring cities from two water-powers 150 miles away. Temporarily, power has been transmitted 220 miles, by connecting the two transmission systems referred to.

Another characteristic of electric power transmission which is important is the high efficiency obtained regularly from electrical apparatus. If 80 or 90% efficiency is obtained from a steam-engine or a water-wheel it is a remarkably good result, but, in a large electric generator, as high as 97% can be obtained, and transformers changing from one potential to another have given more than 98% efficiency.

The efficiency of the power transmission is entirely a matter of how much copper is put in the transmission circuit, but it is seldom that more than 10% is lost in conductors, even with the long-distance transmissions already referred to.

Mr. Gerry does not mention the efficiencies of his apparatus and transmission, but Mr. Thomas is very familiar with the Missouri River plant, and has made many tests upon it. It would be interesting to hear from him as to the results of his experiments, and particularly as to the efficiency of the transmission to Butte.

Mr. Thomas. PERCY H. THOMAS, Esq.—The speaker has spent some time at the plant of the Missouri River Power Company, but, as he has not been connected with the company officially, he is not able to speak authoritatively of what has been done there. A few interesting points, however, might well be mentioned.

The speaker has not seen the figures giving the efficiency of the plant as a whole, but, for purposes of comparison, it can be imagined that power is transmitted from Canyon Ferry to Butte with as little loss as with a fair belt transmission of 15 or 20 ft.

Mr. Gerry has stated that, as far as he knows, this line has the highest voltage in commercial operation, and, probably, he is correct, though another plant which will use the same voltage is being installed and is about to be run.

This Canyon Ferry plant is remarkable in a number of ways: It is remarkable as to the country through which the transmission line passes; it not only crosses three mountain ranges, but one of these is the Continental divide—however, it is not the only line which crosses that divide. It is subject to very great changes of climate and temperature, and passes through extreme ranges of altitude. Lightning, in certain parts of the country traversed, is very severe, and Mr. Gerry says he has noticed, near Helena, that the lightning—sometimes very severe discharges—generally comes out of a clear sky. The rain follows, but by that time the danger is over. At this plant there is great difficulty in getting intelligent electrical men of the various grades, as they are not very plentiful in that part of the country.

In spite of all these difficulties, and many others, Mr. Gerry has succeeded very well. On March 7th, 1903, the plant will have completed a year's commercial operation. The continuity of service seems to have been very satisfactory, though the load handled, *viz.*, large motors, is of a type which is generally considered very difficult. The work in Butte has been the running of compressors, pumps, concentrators, etc. The street railroad is run by another plant.

The following is a feature which, perhaps, is somewhat interesting to civil as well as electrical engineers. Consider one of these 70-mile transmission lines charged up to the pressure of 50 000 volts; the energy stored therein, or that required to bring it to this condition, is about equal to 1 B. T. U. It seems remarkable that such a long line can be charged with so small an amount of energy and to such a high potential. Not only is this true, but it is also found, in practical service on such circuits, that the charging and discharging of this small amount of energy in some unexpected direction, as by accidental short circuits, cause some of the greater difficulties of operation.

During the summer of 1902 Mr. Gerry and the speaker made a number of tests on this plant, trying to determine some of the resultant strains on the apparatus caused by a discharge of this British

thermal unit in an unexpected direction, for instance, such an action as might be brought about by a tree falling across the wire. Mr. Thomas.

Mr. Gerry almost has the record for continuous service on a transmission line at his Helena 12 000-volt plant. At no time during 24 or 26 months was the potential off the bus-bars at the substation in East Helena. That is a record which is difficult to equal in almost any kind of power work.

The question as to the possible effect of such a transmission line as this on long-distance telephone transmission is interesting. The telephone and high-tension lines are parallel for a number of miles. The power lines are 78 ins. apart and the telephone line, which is placed upon one of the two pole lines, is not much more than that distance from the lowest wires, but is pretty well up on the pole. Before Mr. Gerry started to operate his plant the man in charge of the long-distance telephone system feared that the high voltage would interfere with his work, and made a particular request that he be notified before the plant was started. By some oversight the plant was started without notifying him, and had been running for two weeks before he discovered it. Thus it can be considered that there is no very great danger—at least during normal operation—from the parallelism of such lines.

Mr. Gerry has introduced one important feature in the construction of his pole line which may or may not be new. In running his wires over the country, he did not follow the slopes of the land in detail, but put in short and tall poles in such a way that the wires run on smooth grades and thus strains on the insulators and pins are avoided. In going over a summit he rounded off the top so that the highest pole carries no excessive weight.

W. B. Potter, Esq.—How best to secure a maximum result with a minimum expenditure is an ever-present problem with the engineer. For short distances the economy of electrical transmission is limited by the mechanical strength of the transmission lines necessary for reliability; and a high economy of transmission can usually be secured at relatively low voltages. Over long distances the size of the wire may still be that necessary for mechanical strength, provided the voltage is increased correspondingly. Mr. Potter.

The installation described by Mr. Gerry is of particular interest as showing what can be accomplished at 50 000 volts, and the details and precautions taken to insure against accidental grounding of the transmission circuit. The speaker has been much interested and pleased to hear, through Mr. Thomas, of the reliability and efficiency of the service given. It is creditable to Mr. Gerry and the designing engineers of the power-station and substation apparatus that these results have been secured at what but a few years ago would have been considered an impracticable voltage.

Mr. Potter. Mr. Thomas has informed the speaker that, as far as he knows, the 78 ins. between transmission lines has proved ample to protect them against an arc being maintained in the event of its being established accidentally.

At one time it was considered that about 1 in. per thousand volts would be sufficient, but, assuming, for mechanical reasons, a minimum distance of 18 ins., recent practice indicates that about $1\frac{1}{2}$ ins. per thousand volts should be allowed, principally on account of the possibility of an arc being maintained between the wires in case it should be established accidentally. The speaker knows of several instances where the ubiquitous boy has derived much pleasure, and a display of fireworks, by throwing a wire across the lines. The arc thus established would be maintained and travel a considerable distance in the direction of the wind before being extinguished. The speaker believes it is a matter of record that, in one of the western systems, the transmission line was short-circuited, and the power-station shut down, on account of two large birds alighting on adjacent wires and endeavoring to communicate. They succeeded in establishing the connection, to their own undoing. It is perhaps a point worthy of consideration to take due account of the dimensions of the birds in the territory through which the lines may pass, and this suggestion is not necessarily confined to our western States.

Mr. Gerry mentions that the high-potential wiring within the stations is rubber covered, although the insulators on which it is mounted are evidently the main reliance for insulation. As the rubber covering on the wire can hardly be considered a protection, would it not be safer to run the wires through brick or cement compartments, in which case the wires could be left bare and thus lessen the quantity of inflammable material?

The term "load factor" has been mentioned several times, and it has been the speaker's experience that the exact meaning of this term is sometimes misunderstood. Many power-stations have reserve apparatus, which is not operated during the 24 hours, and he has found that there is a difference of understanding as to whether load factor is the percentage of average load to the machines in operation for the actual time they may have been running, or to the installed apparatus. The former is the usual and proper definition, and the speaker would suggest the term "station factor" to represent the average output, in percentage, of the total capacity of the apparatus installed.

The transmission of electrical energy is the solution and problem of electric power for the movement of traffic. The location of water-powers and the economy of steam-power necessitates generating power in large quantity and distributing it to the points of application. Instead of direct-current power-stations, 10 miles apart, and operating

at a low load factor, alternating power-stations are now being built which transmit at high potential to substations 10 miles apart, more or less. Depending upon the character of service, the range covered by a given potential will vary from 1 to 2 miles per thousand volts; that is, if the service were subdivided and the cars of medium size, a 50 000-volt transmission, with the power-station located in the middle, would operate economically a railway 200 miles long, the limitation, of course, being the power required by the most distant substations. Mr. Potter.

The speaker believes that an unprecedented development in the railway field may be looked forward to during the next five years; and the problem of "high-voltage power transmission" will be one of the most interesting with which the engineer will have to deal.

J. R. McKee, Esq.—The speaker has the good fortune to belong to the same department in an electric company as that with which Mr. Blackwell is identified, and for all engineering questions has been in the habit of looking up to him. Mr. McKee.

The question: Can you transmit power electrically over very long distances? has been asked very frequently. It is only a very few years ago that doubt was expressed as to whether power could be transmitted economically over what are to-day such comparatively short distances as 10 or 20 miles.

The limitation to-day, in the handling of electricity for the transmission of power, is more of a mechanical than an electrical problem, and is confined largely to securing an insulator capable of withstanding the very high voltage necessary for economical, or, in other words, commercial, transmission over great distances, such as anywhere from 100 to 500 miles.

One particularly interesting feature in this plant is the use of a glass insulator for a 62-mile transmission over a wire carrying current at 40 000 volts. The speaker thinks there are but two plants in the United States where dependence is placed upon glass insulators for high voltage. One is at Provo, Utah, where, at times, a line has been coupled up for 130 miles, and where a voltage as high as 50 000 was used experimentally, although the normal operative voltage is about 40 000. The second plant transmits at 40 000 volts, 62 miles, from the Madison River to Butte, Mont.

Originally, the question of carrying current over long distances was largely dependent on the possibility of securing a transformer which would withstand a high voltage. Only a few years ago—say five or six, without stating it at all definitely—the electric companies did not care to undertake anything higher than 20 000 volts, and then their guaranty was that if they did not at first succeed, they would not stand for damages, but would try again. To-day, transformers are constructed and have been put into operation for as high as 100 000 volts, and, no doubt, as the art progresses, even higher potentials will be handled safely.

Mr. McKee. The attention of those who are interested in hydraulic work should be directed to the excessive cost which, unfortunately, is shown by so many of the first transmission plants, and which, in nearly every case, has been due to a misunderstanding of the hydraulic features.

The installation of water-wheels connected directly to the generators seemed to call for different methods or rules of calculation, as against those used in ordinary mill plants, where the load is not as variable and where the necessity for close regulation is not as great. The result has been that many of the earlier hydraulic plants, installed for the generation of electricity for transmission, have had to be overhauled, and, naturally, at very great expense, both as to actual expenditure and loss of time.

In one prominent plant the power-house is one of the most substantial granite structures to be found anywhere, and the hydraulic part of the entire plant cost nearly $500 000, but recently it has had to be altered, at a cost of not less than $100 000, because the water could not reach the wheels freely enough to take care of the varying load on the generators with sufficient promptness to give the necessary regulation.

In still another plant, costing more than $300 000 for the power-house, more than $75 000 has been spent in trying to get the water to the wheels more freely, the trouble being that the wheel-chamber was too small and the draft tubes not quite liberal enough in capacity to provide and carry away the water, respectively, when there was a sudden and large variation in the load, and to do it promptly enough to insure the regulation which is necessary in an electric plant.

Comparatively few people realize the extent to which water-powers are being depended upon to solve the question of cheap power, and also the rapid increase in the number of plants of this character. A very interesting installation is that at Salt Lake City, where, starting with a small transmission plant about 15 miles from Salt Lake City, they afterward put in a second plant, near Ogden, carrying the water through a 6-mile pipe line to the power-house and transmitting it 36 miles to Salt Lake City at 30 000 volts, an accomplishment which at that time (about six years ago) was considered very little short of wonderful. Both transmission plants are operated in synchronism with the steam station located at Salt Lake City.

At Butte, Montana, a plant installed on the Madison River, 62 miles distant, is transmitting over a line of aluminum wires at 40 000 volts, and delivering current to the bus-bars of the Butte Lighting Company in synchronism with current brought over another line of 21 miles from a water-power on the Big Hole River, and also with current generated in a steam plant in Butte.

The street railway and lighting system of the Cities of Seattle and Tacoma are operated largely by current brought 42 miles, over an

aluminum wire, from a water-power on the Snoqualmie River. An additional water-power plant, located about 30 miles distant, is now being installed, in which 15 000 H.-P. will be generated for transmission to the same market. A third plant, of not less than 20 000 H.-P., to be installed on a third river, some 35 miles from Tacoma, is under consideration. Mr. McKee.

When these installations are complete, there should be no occasion for the use of any fuel whatsoever for the generation of power in either of these cities or in the locality, there being sufficient water-power to supply all the wants, fuel then being used only where it is required for heat, and the speaker is not absolutely sure but that the cost of electric current, due to the low cost of operating by water-power, may come down to a price so low that even heat can be supplied economically.

Los Angeles, California, one of the centers for oil—in other words, where fuel is cheap—has become one of the greatest transmission centers in the country. There are at present two water-power transmission plants delivering current to this market. One of these is located 85 miles distant, and the other about 20 miles. A third one, located approximately 110 miles distant, is being installed for 15 000 H.-P., and a fourth one, located about 125 miles distant, where they expect to install 20 000 H.-P., is to be undertaken within the next few months. When all these plants are in operation, notwithstanding the low price of fuel at Los Angeles, it is probable that there will be very little steam power used in that city.

The different cities just referred to are only a few of the many in the United States which are being supplied rapidly with electric power generated from water-powers; and, inasmuch as current to-day can be carried distances of 100 to 200 miles economically, it is easy to comprehend how rapidly this method of supplying power will grow. In the spirit of prophecy, the speaker thinks it reasonable to anticipate that it will be only a few years, comparatively, before practically all the power used in manufacturing in New York State, north of a line drawn west from Albany, will be supplied by water power. The possibilities from water stored properly in the Adirondacks are such that, when fully developed, several hundred thousand horse-power of electricity can be generated therefrom for transmission purposes, and with the flood waters held back and stored so as to be released through the usual low-water periods, these water-powers can be made sufficiently uniform to justify their being depended upon for manufacturing purposes; so the rule will be that probably fuel in that section of the State will be used only where heating is a consideration.

With Niagara on the West, the St. Lawrence River on the North and the Adirondacks in the interior, the possibilities for power development are almost unlimited, and the assurance of cheap power equally

Mr. McKee. promising. In the locations where the great developments just mentioned have been made, the natural supposition, particularly at Seattle, would be that there would be a great decrease in the consumption of fuel. This, however, does not seem to have been the case, because, as manufacturing has grown, the increased demand for fuel for use on locomotives and steamships—in other words, for transportation—seems to have more than offset any decrease in its use for manufacturing purposes.

Mr. Gerry. M. H. GERRY, Jr., M. Am. Soc. C. E. (by letter).—Of the greater uses of electricity to-day, perhaps the most important is that of an agency for the transmission of power. It is the connecting link by means of which mechanical energy, generated at distant points, is transferred and again converted into mechanical power under conditions favorable to economical application for commercial purposes.

Mr. Blackwell reminds us of the ease and reliability with which distant generating plants may be worked together, and of the high efficiency attained, as compared with all other methods of transmitting power. These are interesting facts, and are evidence of the desirability and flexibility of the agency under discussion.

Mr. Thomas speaks of the effective lightning protection and successful telephone service maintained on the Butte transmission. His remarks indicate that difficulties recently considered serious have been overcome, and that there is little reason to fear interruptions of the service from such causes on long transmission lines.

Mr. Potter, in his interesting discussion, states that $1\frac{1}{2}$ ins. per 1 000 volts should be allowed between wires on account of the possibility of an arc being maintained if once accidentally established between conductors. The wires on the Butte transmission are placed 78 ins. apart, but for reasons other than those mentioned by Mr. Potter. It is true that an arc will not be maintained at this distance in the open air, under 50 000 volts, nor will it be maintained at a somewhat lesser distance. The wires are so spaced as to control the brush discharges, the electro-static losses, and also to establish a certain line capacity. The rubber insulation of the wires in the station, to which attention is directed by Mr. Potter, is there for the purpose of reducing the brush discharge where the connections are near together, at the terminals of the transformers, and other apparatus. The thickness of the rubber, as stated, is ample to withstand the full electrical pressure. Brick and cement compartments, unless of very great size, are undesirable for high potentials, and even then do not represent the best form of construction.

In closing his remarks, Mr. Potter made an interesting allusion regarding the relation of high-tension electrical transmission to the problem of applying electrical power to the movements of traffic on the present steam railways. An electric railway, primarily, is an

electrical power transmission. Its possibilities and scope have been limited in the past by reason of the use of direct current only, thus restricting the field of operation to comparatively short distances. A combination of alternating-current transmission, with direct-current distribution and application has met with some success in recent years in connection with electric railroading, but this must be regarded as but a temporary expedient, and not as a solution of the problem. There are no inherent reasons why alternating current may not be applied directly to railway service, and thus render possible the general use of electrical power for all classes of railways. There are, in truth, difficulties to be overcome, but they are in reality fewer than confronted the electrical engineers of even ten years ago, in applying direct current to city railway service. Mr. Gerry.

Mr. McKee calls attention to the fact that transformers can now be obtained for electrical potentials up to 100 000 volts. This is certainly a high pressure, but there are no serious obstacles in the way of the use of this voltage on transmission lines where the conditions are such as to warrant the installation. The limit of electrical tension for the transmission of energy has not, as yet, been reached.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 948.

SAND-BLAST CLEANING OF STRUCTURAL STEEL.*

By George W. Lilly, Assoc. M. Am. Soc. C. E.

With Discussion by Messrs. Charles E. Fowler, William Anderson Polk, J. P. Snow, Theodore Belzner, Theodore Paschke, A. H. Sabin, H. B. Seaman, E. A. H. Tays and George W. Lilly.

It is intended to set forth, in this paper, some of the results which have been attained in the use of the sand-blast in cleaning steel plates and structural steel. Some data as to the cost and other elements which enter into its application will be presented, in the hope that possibly something may be added to the facility of making approximately accurate estimates of the cost of any sand-blast cleaning which may be in contemplation hereafter. Some of the work heretofore done has been referred to in a paper, published in *Engineering News* of April 24th, 1902, and in it the cost of cleaning 12 600 sq. ft. of the Front Street Viaduct over the Little Miami Railroad, in Columbus, Ohio, was stated. In presenting the experience gained in the continuance of the work during the season of 1902, giving results in cleaning a total area of 135 500 sq. ft. on viaducts in that city, which have been repainted since the early part of November, 1901, it is hoped to add a record of at least some value.

If it leads to a thorough discussion, and if members of the Society add to the record, the most important part of the purpose in presenting this paper will have been realized.

* Presented at the Meeting of March 18th, 1903.

During the past few years some attention has been given to attempts to secure thorough cleaning of structural steel before the application of the preservative coating; but, unfortunately, we are still far from the realization of the kind of work which should be required. Much has been written relative to the kind of paint which will best preserve the steel and iron used so extensively in a great variety of structures. In the discussion, which has been going on for many years, many have argued very strenuously against, and many just as earnestly in favor of, perhaps, every kind of paint now used largely as preservatives of ferric structures from the ravages of rust and corrosion. But, in the discussion, they have often lost sight of the very important matter of cleaning the steel properly. On account of the great deterioration of such structures, in the past, whether by reason of exposure to the weather on land or at sea, or to the action of acids, or the gases and moisture of coal combustion, in combination with the oxygen of the atmosphere, this is a question of vital interest to all engineers and others concerned in their erection or maintenance. Nevertheless, comparatively little has been done thus far toward securing such cleaning as will insure a much longer life for, as well as economy in the maintenance of, such structures. The dawn of a better day seems to have appeared, in the application of better methods, in some instances, on new work, and, in more cases, on the old; and it is to be hoped that the full light of that day may soon be seen, in the results on new work in the shop—as a provision for the future—and on old structures—to undo, as far as possible, the neglect of the past.

It has often been observed that mill marks made with paint of a very inferior quality have afforded good protection to steel, while other portions, covered with a much better paint, have been much affected by rust, the latter even extending under paint which, for the most part, has still retained its continuity and elastic qualities. The explanation is found in the facts that the mill marks were made when the metal was clean, and that the paint applied subsequently was spread upon the mill scale, rust and grease which had accumulated upon it before the shop work was finished. However excellent may be its qualities, it is absurd to expect any paint to preserve steel to which it is applied, unless the mill scale, rust, dirt and grease have been first removed. This observation applies with equal, or, it may be said, with even greater, force, to the repainting of old structures which have been

neglected, and upon which rust and corrosion have proceeded so far that it is impossible to secure good preservation by ordinary methods of cleaning. Having this knowledge in mind, it is proper to determine, from the conditions met in any case, what is necessary to be done in order to insure that the preservative coating shall be applied only after the surface of the metal is clean and in proper condition to receive it. To accomplish this, there is no doubt that much of the new as well as old steel will be required to be cleaned by means of the sand-blast, as the only practicable and effective method. Much of the steel, after leaving the mills, is stored out-of-doors and exposed to the weather for a considerable length of time before the shop work is done. Thus its rusting often progresses to such an extent that the ordinary process of cleaning with wire brushes, even if that be attempted, is not sufficient to permit the paint to come into immediate contact with and become firmly adherent to the metal. The quality of the paint used, on new structures as well as old, is an important matter; but that cannot be discussed in this paper.

The effectiveness of the sand-blast process depends upon the ability of sand, used as a projectile, to break up, wear away and remove the substances against which it is directed, when actuated by a current of compressed air. All the machines, often called mixers, for the application of this process, are intended to secure the introduction of the proper proportion of sand into a current of compressed air passing through a pipe. This current of compressed air, bearing with it the sand thus introduced, is then directed into and through rubber hose, preferably $2\frac{1}{4}$ or $2\frac{1}{2}$ ins. in diameter, and a steel or iron nozzle of suitable size, and against the surface to be cleaned. Sometimes the air-blast alone may be used to remove dust and soot. Such an appliance was first invented and patented by General Benjamin C. Tilghman, the patent being issued on October 18th, 1870. This appliance, as improved by Mathewson, is still on the market. In this apparatus, a slotted slide, operated by a lever, regulates the quantity of sand introduced into the current of air. This is shown by the sectional drawing, Fig. 1.

In the Paxson-Warren machine, Fig. 2, the feed of the sand is regulated by a revolving piece, or valve, which covers the opening in the bottom of the hopper to the extent desired to let the proper quantity of sand fall through it and into the air-pipe.

In the machine patented by J. M. Newhouse, of Columbus, Ohio, shown in Fig. 3, the sand passes from the hopper at the bottom through an annular opening around the end of a nozzle-shaped steel piece, which decreases in its outer circumference toward the end; and, by raising or lowering it, this annular opening may be increased or diminished in size. The distinguishing feature of this appliance is

MATHEWSON'S SAND-BLAST.
(TRADE NAME, TILGHMAN.)

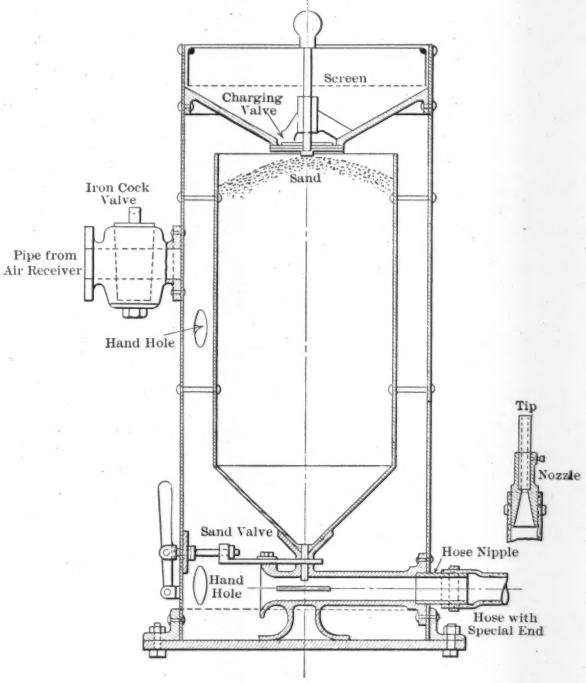


FIG. 1.

the use of this nozzle as a siphon, with its perforations as shown. The small holes permit part of the air which flows through the small pipe and the siphon to escape outwardly through the surrounding sand, thus stirring it up and preventing it from clogging at the opening. A similar siphon, without the perforations, is placed in the air-pipe.

Possibly there are other machines, but the writer is not familiar with them. Any of the sand mixers may be made with two chambers, with valves arranged so as to lock the sand through the upper one into the lower one while the sand-blast is in operation.

The greatest merit of the sand-blast is that it removes from the surface of the metal every trace of dirt, scale, rust and grease, and

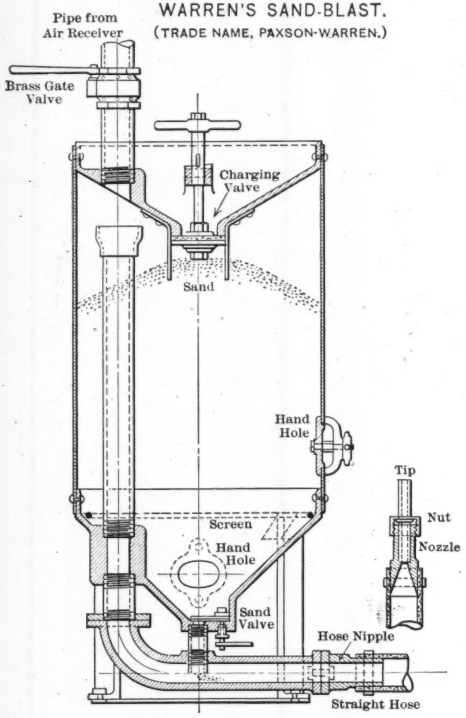
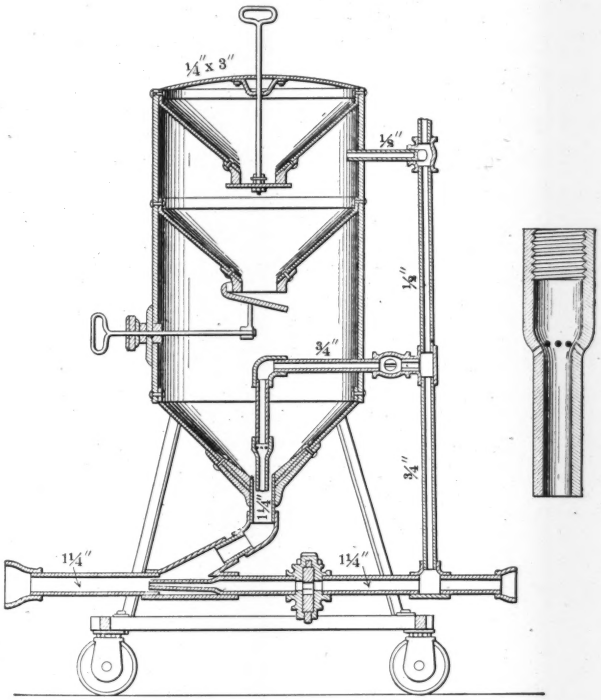


FIG. 2.

the bright metallic surface is everywhere exposed and perfectly clean. This is an ideal condition to secure the strong adhesion of the paint, so that, as far as it is possible, it will protect the metal. The thoroughness of the cleaning effected by the sand-blast is noted especially upon metal surfaces which have been pitted by rust and corrosion to a considerable degree. The pits are thus cleaned as thor-

oughly as other places. It also reaches and cleans effectually every portion, in re-entrant angles and on the edges of the different sections of a beam, girder or post, on and around rivet heads, and in many other places either entirely inaccessible to the wire-brush or steel scraper, or on which they are used with great difficulty and little effect.



THE NEWHOUSE SAND-BLAST.

FIG. 3.

Such places cannot be cleaned thoroughly by hand, even with the most diligent effort. Even plane surfaces of considerable area, on old structures requiring repainting, especially where covered largely with scale and rust, cannot be thus cleaned so as to remove all the dirt, rust, scale and disintegrating paint. There will still remain sufficient rust and scale to separate slightly the paint from the metal,

so that there is not the intimate contact and firm adhesion necessary to prevent the rusting process. The continuity of the coat of paint will soon be broken at places, and, moisture and gases in the atmosphere coming in contact with the metal, rust will be formed even under places where the paint remains intact.

Paint applied to such surfaces can often be stripped off like the peel of an orange, and still remains tough and elastic. Good paint, it may be, but it has never taken a good hold on the steel. On the other hand, the writer has seen a piece of old steel, which was cleaned and painted with red lead in 1899, on which the paint will not peel off at all, but may be cut away, still leaving the under portion tightly adhering to the steel.

The sand-blast has been found serviceable and economical for other purposes than the cleaning of steel plates and structural steel. It is used in cleaning iron and brass castings, either by the direct application of the blast, or by introducing the sand-blast through the hollow trunnion of the tumbling barrel in which the castings are placed. The inner, as well as the outer, surfaces of castings are thus cleaned, and the sharp lines of the edges preserved, while the cleaning effected by the tumbling barrel without the sand-blast tends to round off the corners. Its use to clean street-railway rails and fish-plates, for cast and electric welding, is familiar to all. It is also quite effective in cleaning cut-stone work. One of the ice-manufacturing companies of Columbus, Ohio, has recently purchased a sand-blast machine for use in removing from its condenser pipes the lime scale formed from the hard water used.

The Columbus Railway Company has made use of it in cleaning about 18 ins. in length of a large number of its iron trolley poles, just above and below the surface of the ground. At this point the poles had rusted to such an extent as to weaken them materially, and it would soon have been necessary to replace many of them. After cleaning in this way, a coat of paint was immediately applied, and, soon afterward, each pole was encased in a cylinder of cement mortar tamped into removable forms.

The sand-blast has also been used at the shops of the Pan Handle Railway, and in other railroad shops, in cleaning the tenders of locomotives before repainting. A great saving of expense is thus realized, and superior work is obtained. It would be attempting too much to

take up the methods and relative costs in these various lines of sand-blast work.

It seems that, beyond a few scattered experiments, only during the past six or seven years may be found any published record of the application of this process to the cleaning of structural steel. And, even in these recent years, no very great amount of such cleaning has been done. Most of the trials heretofore made have been upon a somewhat experimental basis, and yet something may be learned from them. It is still rather problematical as to how cheaply the mill scale, rust and grease could be cleaned from new steel plates and structural steel, if an efficient permanent plant were provided for the purpose. Some new plates for the bilge keels of the *Massachusetts* were cleaned at the United States Navy Yard, Brooklyn, in April, 1897. With one nozzle, 3 155 sq. ft. of surface were cleaned in 11 hours. This is at the rate of 286.8 sq. ft. per hour. The cost of the work was 0.56 cent per square foot. Upon this basis the writer estimated that the sand-blast cleaning of new steel plates, I-beams and other sections, would cost from 50 cents per ton, for very heavy sections, to $1.75 per ton, for light sections. This would not be a very large additional expenditure upon steel structures, considering the longer life which it would, no doubt, insure for the steel thus treated. The rapid deterioration and wasting away which has been observed on bridges and other structures may well cause builders of steel-framed buildings to consider the advisability of cleaning the steel in this way, before painting it and hiding it from inspection in the walls. The safety as well as the durability of such buildings may depend upon better provision against the rusting out of these steel frames. Who knows?

The steel for the anchorages of the cables of the New East River Bridge were cleaned by the sand-blast, under the direction of L. L. Buck, M. Am. Soc. C. E., Chief Engineer. This was done for the special reason that it would be "buried in the masonry, and would be totally inaccessible for all time." This process was also used on some of the steel in the Boston subways, Howard A. Carson, M. Am. Soc. C. E., Chief Engineer. The writer has no figures as to the cost in these cases.

Much of the expense of repainting in the future would be saved if greater care were taken in securing thorough cleaning at the shops before applying the first coat of paint to new work. If this is to be

accomplished, it will in many cases be found necessary to use the sand-blast; but this will not be done until the purchaser is willing to pay for it; and he must be convinced of its necessity and ultimate economy before he will be willing to do so. When there is a demand for it, the shops will be equipped with the necessary machinery, and will be able to do it more cheaply. At present, one shop has to bid against the other, and, none of them being required to make bids with such cleaning as a part of the specifications, the bids are such that the shops probably cannot afford to clean the steel properly, in some instances at least. They are averse to this process because of the expense of fitting up for it, the delay in getting the work out, and the cost of handling. Therefore the purchaser must be the prime mover in securing such work.

In the cleaning of old structures for repainting, this process has been more extensively applied, and, therefore, there are better data relative to such work than as to the cost of cleaning new steel at the shops. The necessity of its use to preserve old structures requiring repainting is more apparent than the more remote future saving of the expense of its application for repainting, by a much smaller outlay to secure thorough cleaning before erection.

During the latter part of March and the first two days of April, 1897, the bottom of the United States Steamship *Atlanta* was cleaned at the United States Navy Yard, Brooklyn, by means of the sand-blast, the plant used being furnished by Ward and Nash, of 26 Whitehall Street, New York City, who had the contract for the work. Its cost was 4.24 cents per square foot; but the work was done on a more or less experimental basis, and, with the added experience of the past six years, and a more perfect plant, it could probably be done for much less.

The work done on the One Hundred and Fifty-fifth Street Viaduct, in New York City, under the direction of E. P. North, M. Am. Soc. C. E., Consulting Engineer, during the year 1897, is familiar to all.* The cost of this work was reported as averaging about 13 cents per square foot, ranging from 20 cents, at the first, down to a little less than 10 cents, in the latter part of the work of cleaning 50 000 sq. ft. of surface. The pressure of compressed air then used was only about 20 lbs. at the sand-blast apparatus, which is without doubt too low a pressure

* *Engineering News*, September 23d, 1897, p. 198; *The Engineering Record*, September 25th, 1897, p. 356; and other engineering periodicals.

for the efficient removal of scale such as had accumulated there. It would seem, from recent experience, that a pressure of 35 lbs. would have been much more effective. This is true, because the viaduct was covered to a considerable extent with heavy rust scale and four layers of old paint, and a pressure of 35 lbs. would have made the sand projectiles much more efficient in breaking up and throwing off such scale. M. E. Evans, Assoc. M. Am. Soc. C. E., who was in immediate charge, estimated that the 600 000 sq. ft. of the painting surface of the viaduct could be cleaned for about 7.5 cents per square foot. It is quite probable that this could be done now at half that estimate, at least on all portions of the viaduct except the members having a very small extent of surface, where much sand and air are wasted in missing the steel along the edges.

The next work of this kind reported upon was the cleaning of the iron lock-gates and a portion of the aqueduct of the Muscle Shoals Canal, during the years 1898 and 1899, under the engineers of the United States War Department. The first report of this, made before its completion, is found in the House Documents for 1898–9.* This covers the work done to June 30th, 1898; and, on page 1926, Major Kingman states that the cost for cleaning was about 2.3 cents per square foot. In the report† of Sydney B. Williamson, M. Am. Soc. C. E., made after the completion of the work in 1899, the cost of cleaning 49 664 sq. ft., and painting it with red lead, is stated to be $0.0588 per square foot. Allowing a reasonable amount for the painting, it is probable that 3 cents per square foot would be very near the cost of the cleaning alone. In this case the plant was erected on a barge, roofed over, and was very well arranged to accomplish the work. The cost of the plant was included in this statement, and the same plant could be used for continuing such work. This cost was about one-third of the whole cost of cleaning and painting.

During the year 1899 the Pittsburg, Cincinnati, Chicago and St. Louis Railway Company used the sand-blast for cleaning the columns and girders supporting its buildings over the railroad tracks, along the east side of the High Street Viaduct, in Columbus, Ohio. The girders support brick arches, and there are no buckle-plates. They are subjected to the blast, gases and steam from the large number of locomotives passing to and from the Union Depot, and from freight and

* War Department Reports, Engineers, Part 3, p. 1925 *et seq.*
† Engineer's Report, Part 3, p. 2289, House Doc. for 1899 to 1900.

switch engines passing under them at frequent intervals. This company also cleaned part or all of a bridge at Akron, Ohio. No accurate account was kept of the cost and the area cleaned; but, from the best available information, it is estimated to have been about 3 cents per square foot. J. M. Newhouse, the inventor and patentee of the Newhouse sand-blast, is foreman for this company, and his apparatus was used in doing the work.

The City of Columbus, Ohio, has six viaducts in the vicinity of the Union Station, by which the streets pass over the railroad tracks. All the railroads passing through the city, except one, enter and leave the Union Station under the Fourth Street Viaduct near the east end, and the High Street Viaduct near the west end; and some of them pass under each of the other viaducts, one to the west and three to the southwest from the High Street Viaduct. Besides the freight and passenger trains passing under them, much switching is done under each by the yard engines. Hence, all these viaducts have been attacked seriously by rust and corrosion; and, on the portions most exposed to the blast, steam and gases from the locomotives, nearly all the paint has been destroyed and the metal consumed to a considerable extent. The Fourth Street Viaduct has been injured most, and two years ago it was cleaned by hand and repainted. This viaduct was erected in 1891, and was repainted in June, 1894, in September, 1896, and again, at the time mentioned below, in the fall of 1900. When the last repainting was progressing it was found necessary to replace with new ones seventeen of the 7-in. I-beams supporting the plank floors of the sidewalks over the tracks most used by freight trains and yard engines. Fig. 1, Plate XXVI, is from a photograph of three of these I-beams, taken after their removal, after nine years' service. At the time this was done, the lower flange-angles of many of the stringers supporting the buckle-plates under the roadway had been rusted away until very thin; and in places the horizontal legs of the angles had been partly eaten away, so as to narrow them to about half their original width. These, however, were still considered of sufficient section to last for a time, and were not replaced then. The viaduct was painted under a contract, and considerable care was taken in trying to clean it as thoroughly as possible with steel scrapers, brushes, chisels and hammers. The hammers were often vigorously used to jar the scales loose by blows against the steel, and then scrapers, chisels and wire-brushes used to complete the work.

At that time the sand-blast was suggested by the Engineering Department, but was not used. With as thorough work as could be done, many scales, so tightly cemented to the steel that they could not be detached, were loosened, upon the application of the first coat of paint, by the softening effect of the oil acting upon the cementing rust. The paint then applied began to scale in places within six months thereafter, partly due to the inferior quality of the first coat of paint and partly to the rust, soot and scale left upon the steel when repainted. The flange-angles of the floor stringers continued to waste away, and, in the summer of 1902, it was found necessary to replace, by new ones, the two angles of the lower flange on each of ninety floor stringers. The need of this is apparent from Plate XXV, which is from a photograph of some of the angles taken after their removal.

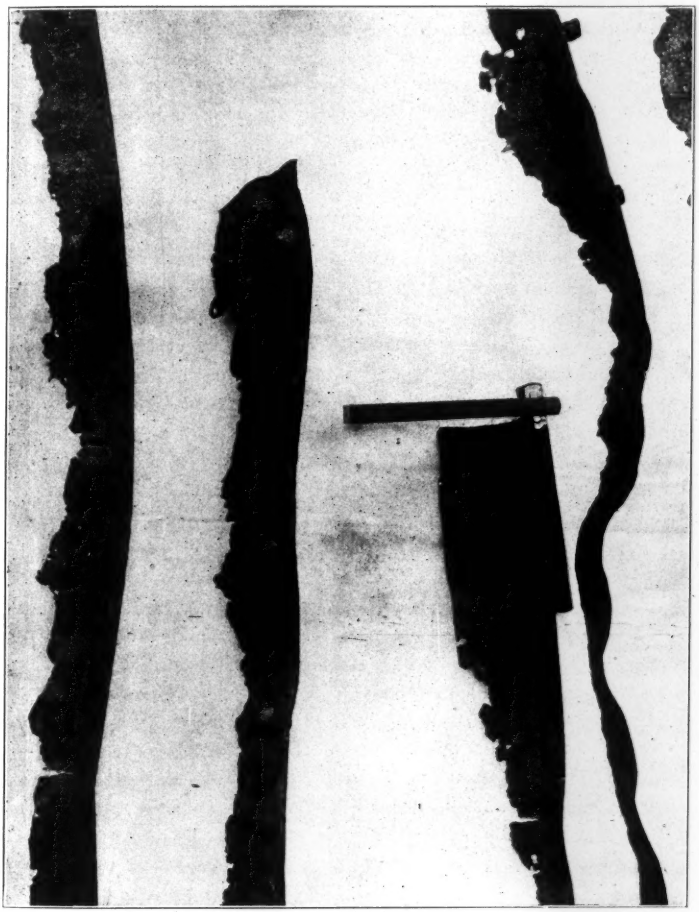
The new angles were surrounded with a covering of Portland cement mortar, 1 to 2 mixture, about ¾ to 1 in. thick. This was rammed under the lower surface of each beam, between it and a plank form, which was left to hold it against the steel until it had set for 48 hours. A wire netting, four meshes to the inch, secured by sheet-iron fasteners placed on the rivets as they were driven, was placed so as to surround the lower flange-angles before the cement mortar was applied. The cement covers the angles and netting completely, and is expected to protect them from rust. After seven months the cement is still intact, and shows no sign of cracking.

In view of the rapid deterioration of the viaducts of the city, and the prospect of having to replace them in a few years unless something were done to arrest it, the city authorities were induced to adopt the sand-blast as a means of cleaning them before repainting. Julian Griggs, M. Am. Soc. C. E., Chief Engineer of the Department of Public Improvements, had been very earnest in the advocacy of this course, believing it to be the only one that would be effective. Accordingly, in November, 1901, the work was commenced on the Front Street Viaduct, over the Little Miami Railroad, and 12 600 sq. ft. were cleaned and repainted, under the supervision of the writer as engineer in charge. When the weather became suitable for it, in April, 1902, the work was resumed and continued on this and the other viaducts named until the middle of November. The cleaning done amounted, in all, to 135 500 sq. ft. of surface. The cost and other data relative thereto are shown in Table No. 1. Four viaducts and

the south span of the High Street Viaduct were completed. It is likely that the other three spans of the High Street Viaduct, and the Fourth Street Viaduct, will be cleaned and repainted during the coming season of 1903.

It was impracticable to secure good contract work at a reasonable price, and all the sand-blast cleaning, as well as the painting, was done by men hired by the day. Two Newhouse sand-blast machines, mounted on light trucks, so that they could be moved about and placed where convenient for the work, were used in cleaning the viaducts named in Table No. 1. A wire-bound, 1½-in., rubber air-hose, 50 ft. in length, connected each machine with the 2-in. air pipe. Old rubber hose, which was much cheaper than new, was used for the sand hose, part of it being 2¼ and part 2½ ins. in diameter. The nozzles used were ½-in., extra heavy, gas pipe, of various lengths, from 12 to 24 ins. A length of at least 12 ins. seems to direct the blast with more effect than a shorter one. This was used instead of tool steel or other hard pipe because it was believed that it would last nearly as long and cost much less. The average length of time one nozzle lasted was about 5 hours, as shown by the length of pipe used and the total hours run. The nozzle was connected to the sand hose by a heavy, special cast reducer, about ¾ in. thick. This is shown in Fig. 2, Plate XXVI, which also shows a blower used at the High Street Viaduct. This reducer was made thick, to sustain the wear caused by the deflection of the sand into the small nozzle pipe. The most severe wear of the nozzles is at a point 3 ins. from the connection with the reducer. The four worn nozzles, in Fig. 3, Plate XXVI, show the characteristic form of the failure of the nozzles when worn out. The one at the right was selected as a rare exception, it being worn out at the outflow end. The three-part nozzle at the left wore out toward the center, and also just outside of the bushing, in which the three ½-in. pipes were set with babbitt metal. This nozzle was made only for the purpose of a test, which is recorded in Table No. 2. After the test, it was used until worn out, and lasted, in all, 1 hour and 19 minutes.

It will be noted that the sand, in passing from the large sand hose to the small nozzle, is deflected so as to produce a cross-fire, striking with greatest force against the sides of the small pipe near the reducer end. A like wear upon the rubber sand hose occurs near its connection with the pipe from the machine, which is a 1½-in. pipe, and the



CORRODED ANGLES FROM FOURTH STREET VIADUCT, COLUMBUS, OHIO.

spreading out of the sand to form the larger stream causes it to strike against the sides and then deflect to follow the direction of the hose. One foot in length, or sometimes a little more, cut from this end of the hose occasionally, fitted it for further use. The length of sand hose used varied from 25 to 65 ft., being regulated by the distance of the work from the place where the machine had to be placed. As the machines could not be placed upon scaffolding, in this work, at least 35 ft. of hose were required on nearly all the work, so as to reach from the ground to the floor system, from 16 to 20 ft. above the tracks, and in some places out over the tracks as far as 30 to 40 ft.

The nozzlemen should be men of some judgment and intelligence, so that they will understand how to manage the nozzle to make the blast most effective. In Fig. 4, Plate XXVI, a nozzleman is shown in costume ready for work. The helmets worn were of tin, with cloth curtains hanging to the shoulders to keep out the dust, as far as possible. Instead of using wire gauze in the helmet, two pieces of glass were used for the nozzleman to see through, because it excluded the dust more effectually. When frosted over by rebounding sand, the glasses were removed and new ones inserted. After a little experience, a good nozzleman will learn how to hold the nozzle in any given case, varying its distance from the working point according to the manner in which he finds it is operating. Heavy scale requires him to hold the nozzle close, and light cleaning can be done more rapidly by holding it farther away and permitting the blast to spread somewhat and thus cut a wider swath. On moderately hard places about 5 to 6 ins. is the proper distance. To make it clean most rapidly he must also direct the blast so as to cut a swath clean as he goes, passing first in one direction and then in the other, across the member being cleaned, so as to leave no spots to which he must go back and thus waste the force of the blast on clean metal around them. The nozzle should generally be directed so as to strike the surface at a slight inclination from the normal, say 20 to 30° away from the nozzleman, thus blowing the dust and sand away. The cleaning should be carried forward from the nozzlemen, so that the blast will always act upon the exposed edge of scales, rust, or old paint, and, by getting under any loose portions, throw them off without first having to break them up.

The compressed air was supplied by the Union Depot Company, from a compressor with an air cylinder of 14 ins. diameter and a stroke

of 12 ins., compressing the air to a gauge pressure of 50 to 60 lbs. The number of strokes was regulated automatically so as to keep the pressure nearly constant. The air was led from the compressor to a large receiver, and then, by a line of 2-in. steel pipe, to a small receiver at the viaduct where the work was to be done. From this receiver (having a capacity of about 9½ cu. ft.) the air was conducted to the sand-blast machines. The pressure at the machines was usually from 30 to 40 lbs. The requisite length of 2-in. pipe varied from about 1 250 to 2 200 ft. The small receiver had a pet-cock in the bottom to let out accumulated water, and it removed much of the moisture from the air used.

The compressed air was paid for by the city, at the rate of 40 and 45 cents per hour for one machine, and 60 cents per hour for two machines in operation. For 18% of the time only one machine was in operation. This made the work cost more, because two machines could have been operated for about one and one-half times what one would cost. A foreman, two nozzlemen and three laborers could operate two machines and dry the sand for them. The foreman was paid 35 cents, nozzlemen 25 cents, and laborers 15 cents during one-half of the time and, after that, 17½ cents per hour.

The sand used was from Lake Erie. An attempt was made to secure rather coarse, clean and sharp sand; but it was at times impossible to do this without some delay, and some of the sand used was too fine and made much dust on account of the silt it contained. The sand was at first dried in two old locomotive ash pans, with old ties for fuel. This required almost constant attendance by one man, to stir it up and keep it from becoming so hot as to make the grains brittle and ineffective.

About May 1st, 1902, the dryer shown in Fig. 1, Plate XXVII, was made by fitting a sheet-steel hopper on an old cast-iron stove. The wet sand would not fall through the ¾-in. holes in the lower part of the hopper, but would as soon as dry. The sand was permitted to cool for a few hours before being used, as hot sand caused steam and was likely to choke the small opening in the bottom of the hopper, around the end of the siphon nozzle. The objection to this kind of a dryer is that the fire-pot, being surrounded by sand in contact with it, burns out in a short time. Two fire-pots were required in six months' service.

All the viaducts named in Table No. 1 have buckle-plate floor sys-

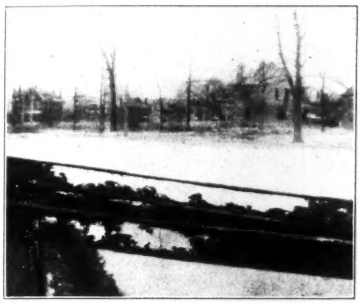


FIG. 1.—CORRODED I-BEAMS FROM FOURTH STREET VIADUCT, COLUMBUS, OHIO.

FIG. 2.—SAND-BLAST NOZZLE REDUCER AND BLOWER.

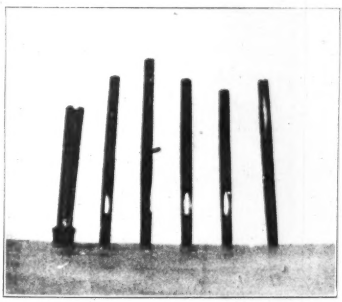


FIG. 3.—WORN-OUT SAND-BLAST NOZZLES.

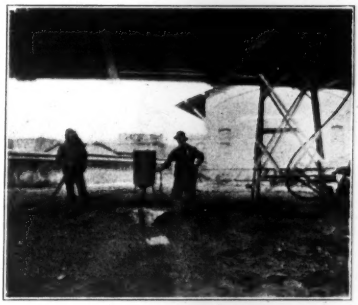


FIG. 4.—SAND-BLAST NOZZLE-MAN, IN WORKING COSTUME.

tems, exposing a large amount of steel surface to the action of rust and corrosion. It may be well to state the conditions under which the work of cleaning had to be done, in order to give a better understanding of the items making up the cost. The data here given may then be better analyzed and applied to any other proposed sand-blast cleaning. The first four viaducts named were erected during 1893 and 1894, and all were repainted during August and September, 1896, and none of them had been repainted since that time. High Street Viaduct was erected in the latter part of 1893, repainted in August, 1896, and again in October, 1899. The cleaning done before repainting, in each of these cases, was only hand-cleaning. All appearances indicate that the steel of the Front Street Viaduct over the Pittsburg, Cincinnati, Chicago and St. Louis, and the Cleveland, Cincinnati, Chicago and St. Louis Railways, must have been in better condition than that of any of the other viaducts, and a better quality of paint must have been applied at the time of its erection. This is judged largely from the condition of the portions of the viaducts above the level of the street pavement and protected by it from the direct action of the blast and gases from the locomotives. The portions below the pavement, on all the others, are subjected to greater wear by the locomotive blast on account of their small clearance above the stacks, their clearance above the level of the railroad tracks being only 16.33 to 16.75 ft., while this viaduct has a clearance of 20.33 ft. In cleaning them, therefore, it was impossible to swing any staging below the clearance elevation, in the case of four of them. The Front Street and the Naghten Street Viaducts do not afford sufficient space above the lower surface of the plate girders in which a man can work, and it was necessary to work from movable trestles, about 12 ft. high, made as light as possible, so that they could be moved off the tracks whenever a train or an engine was about to pass, and be replaced and the work continued when the track was clear. This may be seen in the view of the Front Street Viaduct, Fig. 2, Plate XXVII.

Under the first three viaducts mentioned in Table No. 1, there are two main tracks and one side track, with a spur track from the middle of the first, making four tracks under the east half of it. The photograph of this viaduct was taken from a point very near the outer rail of the side track and west of the viaduct, and does not show the other tracks.

TABLE No. 1.—Cost, etc., of Sand-Blast Cleaning of Viaducts at Columbus, Ohio.

Location of viaduct.	Cost of labor.	Cost of flagmen.	Cost of compressed air.	Sand Used.		Dryer, sand-blast, scaffolding, etc.	Total cost.	Number of square feet cleaned.	Cost per square foot.	Square feet cleaned with 1 cu. ft. of sand.	Square feet cleaned per hour by one sand-blast.	Average pressure at sand-blast, in pounds per square inch.
				Cubic yards.	Cost.							
Front St., over Little Miami Railroad	$385.30	$45.15	$139.40	54.00	$78.55	$56.68	$705.08	94 900	$0.0283	17.1	64	35
Naghten St., " " " "	140.74	17.85	56.40	28.44	42.41	32.52	289.92	8 000	0.0862	10.4	49	37
Maple " " " "	223.09	11.90	94.90	34.50	58.08	58.70	446.48	17 000	0.0263	18.2	66	35
Front St., over Pittsburg, Cincinnati, Chicago & St. Louis and Cleveland, Cincinnati, Chicago & St. Louis Railways	670.66	.....	229.80	92.65	107.43	87.18	1 065.07	63 000	0.0174	25.2	80	30
High St. (South Span)	961.30	.....	319.94	129.91	161.47	122.46	1 555.07	22 600	0.0688	6.1	23	33
Totals and Averages	$2 370.90	$74.90	$840.84	339.50	$447.94	$357.54	$4 091.62	195 500	$0.0209	14.8	54	33
Excluding High St. Viaduct	.....	.....	.....	.....	.....	.....	3 536.55	112 900	0.0225	20.0	74	33

The movable trestles were also used, part of the time, in cleaning the cover-plates on the bottoms of the girders and the portion of the work along the abutments of the Maple Street Viaduct; but a large portion of the cleaning was done from staging resting upon the lower cover-plates and angles of the plate girders. Fig. 3, Plate XXVII, shows a portion of the girders and buckle-plate when all except a small portion of the buckle-plate and the web of the girders, where scale can be seen, had been cleaned and given a coat of red lead. Two more coats, of a paint less susceptible to the action of combustion gases, were applied afterward, as on all the viaducts.

To secure the safety of the men while at work on these three viaducts, when using the trestles over the tracks, it was necessary to have flagmen to give warning of the approach of trains, so that the trestles could be removed in time to avoid the danger. On the Maple Street Viaduct flagmen were not needed for so large a proportion of the time as on the other two viaducts. The cost of flagmen alone amounts to about 0.2 cent per square foot on the first two in Table No. 1, and 0.07 cent on the Maple Street Viaduct. The time lost on account of trains and switch engines sometimes amounted to one-fourth of the working time. If there had been no interruption by trains, and if flagmen had not been required, a fair estimate, from approximate calculations, based on records of the time lost each day and the cost of flagmen would reduce the cost of the work to about the following figures: Front Street Viaduct, 2.3 cents; Naghten Street Viaduct, 3 cents, and Maple Street Viaduct, 2.45 cents, per square foot. Matched flooring screens, fastened with copper nails, were placed immediately over the main tracks and under the floors of these three viaducts, to protect them from the blast from locomotives.

In the Front Street Viaduct, over the Pittsburg, Cincinnati, Chicago and St. Louis and the Cleveland, Cincinnati, Chicago and St. Louis Railways, in which the clearance was 20.33 ft., the staging was supported on iron hangers which reached 2 ft. below the lower flanges of the floor beams. This space, with the 29 ins. more to the buckle-plates, gave room enough for the work, and the staging still gave about 2 ft. more clearance than the High Street Viaduct, just east of it and over the same tracks. Fig. 4, Plate XXVII, shows part of the north span of this viaduct, over the Cleveland, Cincinnati, Chicago and St. Louis Railway tracks. The portion of the three heavy trusses

above the pavement was in very fair condition, and it was not thought necessary to clean it with the sand-blast. This saved the cleaning of 36 000 sq. ft. of metal surface on this viaduct, while, on the others, practically all was cleaned. A portion of this viaduct, shown in Fig. 4, Plate XXVI, is not over the railroad tracks, and was not affected as seriously as the remainder of the floor system. Some of the paint was still good, and it was not all taken off. This, together with the fact that there was not much interruption to the work, made the cost of cleaning, on this viaduct, less than on any other, all the others being much affected with rust, scale and corrosion upon nearly all parts of them, even above the level of the pavement, where protected from the direct action of the gases.

The south span of the High Street Viaduct, the portion already cleaned, is over the main freight and passenger tracks, and yard engines pass under it frequently. The other spans can be cleaned for very much less than this one. It has been estimated by men who are in the employ of the Pennsylvania Railway Company that an average of from 250 to 300 engines pass under this span every 24 hours. The girders and buckle-plates were in very bad condition, and very heavy and exceedingly firm scale had been formed over large portions of them. This scale was firmly cemented to the steel by the rust and carbonates which had formed. As a consequence, the sand-blast did not blow off much of it, nor did it work under the scale and throw it off, as on the other viaducts. Therefore, it cost nearly twice as much as the highest of the others, and nearly four times as much per square foot as the large Front Street Viaduct. The floor system is similar to that of the Maple Street Viaduct, the pavement being supported by seventeen plate girders. Immediately east of this is the structure under the roadway to the Union Station, also having seventeen plate girders. The distance over both is about 165 ft., and this, with the girders extending 3.5 ft. below the floor, causes the smoke to hang a long time between the girders after an engine has passed beneath. Often, it does not clear away before another engine comes along and again fills all the spaces with dense smoke. The smoke, and the dust from the sand-blast work, therefore, caused a great deal of trouble. It was very difficult, and part of the time impossible, to get nozzlemen to keep both blasts in operation. To get rid of the smoke and dust, an electric fan was tried for a short time, it being

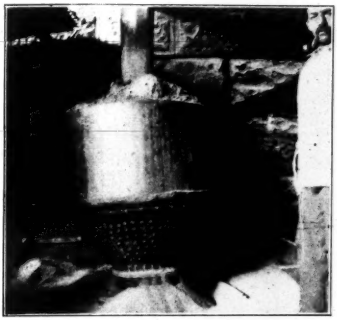


FIG. 1.—SAND DRYER.

FIG. 2.—FRONT STREET VIADUCT, COLUMBUS, OHIO.

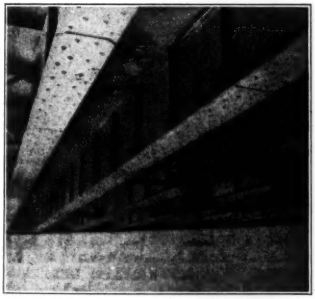


FIG. 3.—PART OF GIRDERS AND BUCKLE-PLATES OF MAPLE STREET VIADUCT, COLUMBUS, OHIO.

FIG. 4.—PART OF NORTH SPAN OF FRONT STREET VIADUCT, COLUMBUS, OHIO.

placed near the abutment between the girders where the work was progressing. This kept the smoke from rising, and cleared away the dust quite well; but the bearings were injured very much by the dust and fine sand. Then the blower shown in Fig. 2, Plate XXVI, was made. This was connected with the air pipe by a $\frac{1}{2}$-in. rubber hose, and a jet of compressed air, passing through an opening of about $\frac{1}{32}$ in., and into and through a section of 5-in. sheet-iron pipe, about 2 ft. long, set up a current of air, which, being directed along between the girders, was quite effective. One of these was made for each sand-blast, and they were used for a considerable portion of the time. Smoke and dust, however, would gather behind the blower and be drawn through it at times, and it was not a complete success. It was effective for a distance of about 20 ft.

Another cause of the high cost of this work was the low pressure secured at the sand-blast machine during much of the time. The operation of the blowers tended to reduce it, and the compressor was worked beyond its intended capacity, and was not at the time doing as good work as earlier. The average pressure, at this viaduct, as stated in Table No. 1, is partly an estimate, as the gauge was broken and for a portion of the time was not in use. When at 30 lbs. or less, the sand-blast was very slow in cutting the scale here encountered; but when at 38 to 40 lbs., it was much more efficient. Occasionally, when only one blast was in operation for a short time, the pressure would run up to 45 lbs., and then the effect was still better.

From the experience in sand-blast cleaning here given it may be safely stated that, for heavy scale and corrosion, in situations such as this High Street Viaduct, a pressure of from 35 to 45 lbs. per square inch is not any too high. On the other hand, very efficient work is done at a pressure of about 25 lbs., where only light scale, rust spots and disintegrating paint are to be cleaned off. The labor costs approximately twice as much as the power, and increase of power is advisable where needed.

On all the cleaning done, the bright surface of the steel, having almost the appearance of frosted silver, was exposed to view by the removal of every vestige of rust, scale and old paint. The pitted portions, with a little more brushing, were as well covered with the paint as the others, and, after one year, it still holds on them as firmly, to all appearances, as when it first dried, after being put on.

The paint was applied very soon after the sand-blast, and sometimes curtains of heavy muslin were stretched between the painters and the sand-blast to prevent the dust and sand from interfering with the painting. All surfaces cleaned were painted before night, and rarely was it necessary for the painters to work more than half an hour after the sand-blast was discontinued for the day. It is best to work with the wind, so that it will carry the dust and sand away from the painters and nozzle-men.

Some records of actual results are shown in Table No. 2, both in the ordinary work of cleaning, and on tests in which an accurate account was taken for all the data presented therein. In some of these records there are omissions because all the elements were not noted. The long-time records give only the surface cleaned, and not the sand used or the horse-power necessary; and the two, showing results as to the whole work, are included for the sake of comparison. In these two are given some other results of calculations, from known quantities and records, which represent rates for one sand-blast, although two were running about 82% of the time. The number of hours stated is obtained by adding together the number of hours run by each machine. The tests of October 16th and 31st, 1902, were made in order to determine the relative effectiveness of nozzles of different diameters, from $\frac{1}{4}$ to $\frac{3}{4}$-in. in size. The sizes of pipe given are the nominal sizes of gas pipe, with "Ex. H." added where extra heavy gas pipe was used, which, of course, is smaller in interior diameter than standard gas pipe. The last one noted was with a nozzle (Fig. 3, Plate XXVI), made from three $\frac{1}{4}$-in. gas pipes, one end of each being inserted in a $1\frac{1}{4} \times 1$-in. bushing, and babbitt metal poured in to secure them there. While only made for an experiment, this nozzle gave very good results, it having the highest rate of cleaning, in square feet per hour. It used considerable sand, about the same as the $\frac{3}{4}$-in. pipe, but cleaned nearly one-half more.

All these tests were made on the High Street Viaduct, where, for all of them, the corrosion was, as nearly as possible, of the same character. The rates of cleaning are low, because, on this viaduct, the scale was so hard. These tests of nozzles were made with a sand hose 65 ft. in length. All the nozzles for these eight tests were 12 ins. long. It will be seen from the results that the $\frac{1}{2}$-in. extra heavy pipe, which is $\frac{3}{4}$ in. when worn out, is about the proper size for this kind of work.

TABLE No. 2.—Data as to the Operation of the Sand-Blast; and Tests of Nozzles of Different Diameters, at Columbus, Ohio.

Date.	Duration.		Nominal size of gas pipe nozzle.	Air Pressure.		Cubic feet of free air per minute.	Horse-power required.	Cubic feet of sand used.	Area cleaned, in square feet.	Square feet cleaned per cubic foot of sand.	Rates per Hour.		Remarks.
	Hours.	Minutes.		At compressor.	At sand-blast.						Cubic feet of sand.	Feet cleaned.	
1899.													
Sept. 27.....	....	29	½"	..	35	170	20.4	1.52	110	72.5	3.14	227.6	Pittsburg, Cincinnati, Chicago and St. Louis Railway work.
1901.													
Nov. 14.....	....	55	½" Ex. H.	50	35	170	20.4	6.60	144	21.8	7.20	157.1	Plate girder, considerably rusted.
" 16.....	....	26	½" Ex. H.	50	36	...	....	2.20	77	35.0	5.10	177.7	Plate girder, paint nearly destroyed.
" 14.....	4	45	½" Ex. H.	50	35	170	20.4	.....	375	....	....	79.0	Plate girder (includes lost time).
" 16.....	3	..	½" Ex. H.	50	36	...	....	.....	322	....	....	107.3	Plate girder, paint nearly destroyed (includes lost time).
" 18.....	7	50	½" Ex. H.	50	36	...	....	.....	655	....	....	83.6	Plate girder, paint nearly destroyed (includes lost time).
" 19.....	7	30	½" Ex. H.	50	35	...	....	.....	825	....	....	110.0	Plate girder, paint nearly destroyed (includes lost time).
" 20.....	7	30	½" Ex. H.	40	25	...	....	.....	1 227	....	....	164.0	About 10% of paint good and not removed (includes lost time).
Dec. 7.....	13	30	½" Ex. H.	48	33	...	....	.....	1 000	....	....	74.1	Floor system over railroad tracks (includes lost time).
Nov. 14th, 1901, to Aug. 13th, 1902...	1 519	..	½" Ex. H.	..	33	...	....	5 658.9	112 900	20.0	3.72	74.3	First four viaducts in Table No. 1.
1902.													
Aug. to Nov..	999	..	½" Ex. H.	..	33	...	....	3 507.6	22 600	6.4	3.54	22.8	High Street Viaduct, see Table No. 1.
Oct. 16.....	....	18	½" Ex. H.	55	37	156	18.7	1.40	11.80	8.4	4.67	39.33	High Street Viaduct, test run.
" 16.....	....	24	3/8"	55	37	140	16.8	1.31	6.65	5.1	3.28	16.63	High Street Viaduct, test run.
" 16.....	....	27½	¼"	55	39	108	13.0	1.20	2.42	2.0	2.62	5.28	High Street Viaduct, test run.
" 20.....	....	27	½" Ex. H.	..	35	...	....	3.30	18.70	5.4	7.67	41.60	High Street Viaduct (another blast running).
" 31.....	....	7¼	3/8"	55	40	200	24.0	1.10	4.25	3.9	9.10	35.20	High Street Viaduct, test run.
" 31.....	....	18	½" Ex. H.	55	41	170	20.4	2.20	14.00	6.4	7.33	46.67	High Street Viaduct, test run.
" 31.....	....	9	3/8"	55	42	156	18.7	1.10	6.60	6.0	7.33	44.00	High Street Viaduct, test run.
" 31.....	....	24	¼"	55	43	130	15.6	1.00	4.75	4.7	2.50	11.88	High Street Viaduct, test run.
" 31.....	....	7	¼" (Three)	55	41	176	21.1	1.16	6.60	5.4	9.43	51.40	High Street Viaduct, test run.

Improvements can certainly be made in this apparatus. Some of the appliances were made as experiments, and are rather crude. One observation may be made which will occur to all, that more sand-blasts might be added with advantage, if sufficient power to run them were provided. The work at Columbus was limited to two machines, on account of the small capacity of the compressor. Perhaps a larger pipe to convey the air would have added to the pressure at the machines, and to the effectiveness of the sand-blast. For ordinary cleaning of bridges and other structures, not subjected to such hard treatment as viaducts situated where much exposed to the blast and gases from locomotives, it is safe to say that, with a more perfect equipment, sand-blast cleaning can be done at from 1¼ to 2 cents per square foot. The advantages anticipated for this kind of cleaning, especially where almost a necessity, because nothing else will do the work thoroughly, are to be gained by a careful inspection at intervals after it is done, and the repainting, with ordinary, good hand-cleaning, before the paint has been worn off so as to set up the vigorous rusting process which comes when air and moisture get to the metal. In such locations as the viaducts in Columbus it seems to be the only thing that will do the work. For future construction in similar locations let every engineer beware of the use of steel exposed to locomotive blasts, as these will wear out any paint. The life of those structures already in existence, and others which may be built in the future, should be extended as long as possible by the use of the best means that can be commanded.

DISCUSSION.

Mr. Fowler.

CHARLES EVAN FOWLER, M. Am. Soc. C. E. (by letter).—This paper is certainly one of the most important that has ever been presented before the Society. The failure to clean the metal of steel structures properly before they are painted is the principal cause of their deterioration, and, practically, is the only cause which exists as a prejudice against them. While the bridge shops have, in most instances, endeavored to clean the steel properly before paint is applied, it has never been done satisfactorily, in the majority of cases, owing to the character of the plant used, and owing to the character of the help which it is necessary to employ on work of this kind. The laborers ordinarily employed as painters about bridge works are not possessed of a very high order of intelligence, and soon fall into the rut of glossing over and slighting their work. When they are discharged, and new ones put in their places, there is always a length of time for breaking them in, during which the work is not done properly, so that the writer believes that, necessarily, it must come to some such method as sand-blast cleaning at the bridge shops before painting is done, or else follow the lead of some European railroads, where the bridges are not painted until some time after erection.

The specifications of the Sheffield and Lincolnshire Railway Company for 1889 require that no portion of a structure shall be painted before erection, except such parts as are not accessible for painting afterward. Some time after the structure is erected, and the scale has all disappeared by rusting off, the metal is cleaned thoroughly and painted. Should this be done by the sand-blast process, and paint at once applied, there would be some surety of a proper protection from future rusting.

Many engineers seem to object to allowing rust to appear upon the steel at all, preferring to have the metal kept under cover from the time it is rolled until it is fabricated and painted, but anyone who has had experience with raw steel plates and shapes stored in a yard, will know that the mill scale, which very often is not removed otherwise, is rusted off, and the solid metal, although coated with rust, can be gotten at so as to be cleaned thoroughly and painted; whereas, if the metal is kept under cover, much of this scale remains on and is painted over, and in a few years flakes away from the metal, or rusting between the scale and the body of the metal goes on unseen.

In the writer's opinion, particular parts of bridges should be galvanized, in a great many cases, or protected by Barffing, so as to give them a protection once for all; but, in lieu of this, the thorough cleaning of existing structures by a method similar to that used by Mr. Lilly should be followed, and the coating applied directly afterward

Mr. Fowler. to protect the steel thoroughly. In such cases it will be possible soon to arrive at some definite idea as to which paint is really the best to use on bridges and steel structures.

While not directly a feature of Mr. Lilly's paper, it certainly is one which comes up in studying it, as to what kind of paint is really the best. The writer is not prepared to change his opinion, formed during many years as Chief Engineer of one of the large eastern bridge companies, that red-lead paint is the best that can be applied, regardless of the numerous paints which are advertised so loudly as the best for protecting steelwork. Red lead, used according to the Baltimore and Ohio specifications of 1896, by the addition of 10 oz. of lampblack to every 12 lbs. of red lead, can be handled as easily as any other paint. Next to this, for first-class work, are the various carbon paints put on the market by the standard paint companies.

While the writer has no data of his own, as to the cost of sand-blast cleaning, it appears from the paper that the cost can be reduced to a reasonable figure, and one which would warrant the use of the method whenever there is a large amount of cleaning to be done.

If this paper shall have served no other purpose than to have called attention in a forcible way to the need of thorough cleaning of steelwork before painting, it will have proved itself to be one of the most valuable papers ever presented for the consideration of engineers having to do with steel structures.

Mr. Polk. WILLIAM ANDERSON POLK, Assoc. Am. Soc. C. E. (by letter).—The writer has read this paper with much interest, especially that part relative to cleaning the One Hundred and Fifty-fifth Street Viaduct, in New York City. During this operation the writer had the pleasure of devoting about one month's time to observation of the workings of the sand-blast, and found that it was the only power capable of removing the accumulated rust scale with despatch and economy. Moreover, it was the only method that was thoroughly efficient in preparing the surface for the tests of paints, that being the object for which the sand-blast was used on the viaduct.

To understand how thoroughly the machine did its work, it may be stated that on days in which the humidity was great (such days were frequent, the humidity registering often from 90 to 98°), the metal was no sooner cleaned than the gray color was changed by oxidation to a rusty brown. It was deemed expedient to apply the paint as soon as possible after a sufficient number of square feet (about 200) had been cleaned. This surface would comprise two buckle-plates, one on each side of the girder, and the section of the girder supporting these buckle-plates. The cleaned surface was protected from sand by a screen of sail cloth while the machine was being operated.

Notwithstanding this protection, a great deal of fine dust settled on the cleaned portion. This dust was readily taken up by the paint,

however, and, in the writer's opinion, did no harm. One painter could finish in two hours the portion which had been cleaned by one nozzle-man in eight hours, under favorable conditions, *viz.*, in dry weather and with dry sand. Four nozzle-men could keep one painter busy, but, to accomplish this, the sail-cloth screen had to be moved frequently to places where protection might be necessary. On bridges at other places the writer has noticed that a screen was not needed. Mr. Polk.

The expense of cleaning the One Hundred and Fifty-fifth Street Viaduct was necessarily much greater than it would be to-day. The cost and the time of cleaning could be reduced very much by the addition of more machines.

For the purpose of preparing metal surfaces for painting, nothing has come under the writer's observation, during a period of ten years, that can approach the efficiency of the sand-blast machine. In order to have the best results from painting, it is expedient, nay, it is necessary, to have the surface absolutely free from rust, mill scale and grease; therefore the sand-blast will more than pay for itself in decreased maintenance and in furthering the lasting qualities of metal coatings.

J. P. Snow, M. Am. Soc. C. E. (by letter).—The Boston and Maine Railroad (with which the writer is connected) has used a sand-blast outfit for four seasons, but from its experience little can be added to the testimony given by the author. The mixers used are of the Tilghman pattern, as shown by Fig. 1, with a second hopper, so that sand may be fed continuously while the blast is operating. Mr. Snow.

The air is furnished by a Fairbanks-Morse gasoline compressor, with an 11-in. engine cylinder and a 14½-in. pump having an 18-in. stroke. Two, and sometimes three, open-topped galvanized-iron tanks, of 600 galls. capacity, each containing circulating water for cooling the cylinders, are used; these, and a small galvanized-iron gasoline holder, a boiler-iron air-reservoir, a sand-dryer, and pipes, hose, etc., complete the outfit.

The air pressure with this plant is from 15 to 18 lbs., which is very effective on weather rust not heavily scaled. Where the scale is caused by engine gases or by brine from refrigerator cars it is removed with hammers, chisels, etc., before applying the blast. It is thought that a greater pressure, as advocated by Mr. Lilly, would be more effective where the rust is heavy and the metal pitted. The pressure can be increased by exchanging the pump cylinder for a smaller one.

Usually, this outfit is loaded and unloaded by a car derrick. It is set up near the bridge to be operated upon, the water tanks are filled from the locomotive tender, a detachable shanty is put over the engine, sand is unloaded, the pipes are connected, and work is commenced. It requires only a few hours to set up the plant at a given bridge. It is desirable to have the sand-dryer as near the bridge as possible,

Mr. Snow. but the engine should be 100 ft. away, or further, to get it somewhat out of the dust.

The sand should be clean and hard. For the highest efficiency, its fineness should depend on the kind of rust to be attacked. For simple weather rust, fine sand is the best. If the rust is heavy, the metal pitted and the surface hard to get at, coarse sand should be used. Where the work is over dry land, the sand can be used again several times. It gets finer each time it is used, but, as the impact against the metal breaks the grains of sand, they are sharp, and, until it becomes too fine, its effectiveness is rather greater than at first.

For drying sand a so-called Chicago dryer is used. Its action is similar to that of the dryer shown in Fig. 1, Plate XXVII, except that the dry sand escapes through an annular opening against the fire-box, which prevents, in a measure, the over-heating mentioned in the paper. This method of drying sand is very unscientific, however, inasmuch as the mass of sand in the hopper acts as a blanket to prevent the escape of steam from the lower portion next to the fire-pot, where there is the greatest heat. In fact, it is a good deal like trying to drive moisture out of a steam-tight box. A dryer, arranged so that the sand could fall over a series of inclined baffle-plates in a furnace, where the heated gases from the fire could pass over a thin moving sheet of sand and absorb its moisture, is a desideratum. The waste heat from the engine exhaust is enough to dry the sand in a properly arranged dryer, but there are practical difficulties in using it. The exhaust from an explosion engine should be free and close to the engine, to obviate back pressure; but, to save the running parts, the engine should be at some considerable distance from the sand. Again, it is frequently desirable to dry sand when the engine is not running; therefore, on the whole, it seems best to use an independent dryer.

Some difficulty is experienced from moisture carried by the condensed air. A very little dampness will cause the sand to clog at the lower valve, as mentioned in the paper; but, with drips at the air reservoir, and no sags in the lines of air pipes, the trouble is not great.

In cleaning a long bridge the air has been carried as far as 900 ft. from the reservoir. A 3-in. pipe is used, and there is very little reduction in the pressure from the reservoir to the mixers.

The operation of painting is similar to that described by Mr. Lilly. On overhead bridges, which suffer from the blast action of the locomotive smokestacks, it is not considered a disadvantage to have the sand get into the raw paint. Two coats are applied, and the portion directly over the centers of the tracks receives three coats. If the first is well filled with sand the result is a thick, gritty coat, which has considerable power to withstand the blast of hot sparks from the stacks.

With the engine described, three mixers and nozzles are used. The force required is generally a foreman and six men; three on the nozzles and three drying sand and feeding it to the mixers. The writer has no reliable statistics as to cost. The figures given in the paper are fairly comparable with average results obtained, but many jobs cost more on account of the difficulty of getting at the parts to be cleaned. The question simply resolves itself into a choice between letting the metal waste away at its own rate, or paying the cost of cleaning it with the sand-blast. Where iron has become heavily scaled by locomotive gases, brine from beef cars, or sea water, it is simply impracticable to stop corrosion by any method, known to the writer, other than the sand-blast. Mr. Snow.

THEODORE BELZNER, Jun. Am. Soc. C. E.—In this paper Mr. Lilly has carefully covered the ground, and has left little to be added except practical experiences in the same line. A number of his recommendations should be carried out, and, if criticism were to be made, it would have to be said that he does not place sufficient emphasis on some of his recommendations. Mr. Belzner.

The speaker will endeavor to relate the experience gained in the sand-blast cleaning of steel on the Rapid Transit Subway, in New York City.

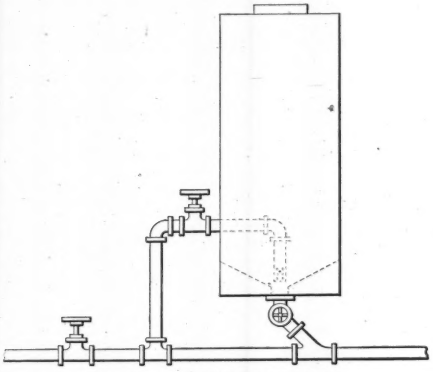
Owing to the magnitude of the Rapid Transit Subway work, steel had to be ordered largely in advance from the manufacturers, who in this case were the American Bridge Company. Such steel as columns and girders of standard size and design were ordered, so as to facilitate the output at the mills. Large quantities were received, and lay for from eighteen months to two years, piled high in the streets and at the yard at the foot of Forty-second Street, East River. This steel was exposed to the inclemency of the weather for that period. When the sub-contractors were ready to use the steel it was found that the paint had worn off considerably, and a part of the steel was corroded. It was determined to clean and repaint before erection such parts as were to be exposed in the structure, and all abutting and connecting parts which were not to be embedded in concrete. S. L. F. Deyo, M. Am. Soc. C. E., Chief Engineer for the Rapid Transit Subway Construction Company, acting on the recommendation of William Barclay Parsons, M. Am. Soc. C. E., Chief Engineer for the Rapid Transit Commission, then gave the order to the sub-contractors to clean the steel with the sand-blast.

Before taking up the work in detail it should be stated that the various sub-contractors had established air-compressing plants on their various sections, thus having their line covered with compressed-air pipes.

A large quantity of steel was piled at Canal and Elm Streets, and work was commenced there, but was found to be such a nuisance to

Mr. Belzner. the tenants of surrounding buildings and to traffic that it was moved down into the partly-finished subway. Here the dirt and sand became a hindrance to the workmen, and the work was moved to Bond and Elm Streets. Here, again, it proved to be such a nuisance to the public and to traffic that the operation of the blast was confined to night hours. Work was then carried on at this point for a long time until the street was cleared for paving. The plant was then moved to Forty-second Street and the East River, where, again, work during the day was found to be objectionable to the neighborhood, and the work is now being done at night.

The plant, after being moved to Forty-second Street and East River, was entirely rearranged, and in such a way as to obtain much better results than those obtained previously. The size of the pipe from the condenser to the blasts was increased to 1½ ins., and a much greater



SECTION OF SAND-BLAST TANK.

FIG. 4.

pressure was obtained, thereby largely increasing the quantity cleaned. The tanks were about 200 ft. from the power-house. The arrangements for drying and storing sand ready for use were also improved, and the handling was facilitated considerably by the use of the crane in lifting and piling the steel.

Two plants are at work: That for The Degnon-McLean Contracting Company consists of four tanks of double-row, riveted, extra heavy, ordinary kitchen-boiler, 14 ins. in diameter and 4 ft. 10 ins. long, the interior arrangement of which is shown in Fig. 4. The plant in use by the Holbrook, Cabot and Daly Contracting Company consists of two tanks having a similar interior arrangement.

Although four tanks were erected for The Degnon-McLean Contracting Company, only two are in use, as a rule, the extra tanks being

kept in reserve in case of any trouble, thereby preventing any interruption of the work. Mr. Belzner.

The simplicity of the design of these sand tanks should recommend itself to engineers, because any mechanic can look after them, thus avoiding the use of patented devices such as described by Mr. Lilly.

Great care has been taken in the selection of the sand. That coming from the shores of Long Island Sound has proved to be the best for the purpose desired. The arrangements made for drying the sand consist of an open brick flue, about 3 ft. wide and 20 ins. high, on which are placed two iron trays. These trays are of ¼-in. iron, and each is 6 ins. deep, 3 ft. 6 ins. wide and 4 ft. long.

Great care should be taken in drying the sand. It should be turned over continually, which in this case had to be done by hand. When dry it should be removed from the pans at once, and not allowed to burn or bake, for in that case when it came into impact with the steel it would be brittle, and, battering into fine dust, would not remove the rust. Sand dried properly and carefully can be used two or three times with good results. In a permanent plant, a rotary dryer, over a fire, or supplied with a hot blast, could be used very economically, and the drying would be more uniform.

A section, about 6 ins. in diameter, was cut out of the crown of each blast tank and a screw cap fitted to the opening. This is removed while the tanks are being filled. The sand is passed through a fine wire mesh before being poured into the tanks, so that nothing can pass through that will tend to choke or obstruct the valves and fittings.

The outlet for the sand is at the bottom and center of the tank, and is of 1½-in. pipe connecting below with the air-pipe at an angle of about 45 degrees. About 6 ins. above the outlet another connection is made through the side of the tank by a 1-in. pipe extending to the center of the tank, with an elbow, the end looking down into the outlet. This pipe and elbow are perforated with small holes, and air under pressure, and controlled by a valve, is admitted so as to keep the sand slightly agitated, thereby facilitating its flow through the outlet.

The sand flows from the tanks through a flexible rubber hose of 2½ ins. internal diameter, to the end of which is attached an ordinary pipe reducer to receive the nozzle; it passes out at a uniform pressure of 65 lbs. per square inch. This pressure is furnished from the power-house erected for the purpose of supplying power for the work being done on Park avenue and Forty-second Street.

In front of the tank a platform of 2-in. lumber, 25 x 50 ft., was built. On this the pieces of steel are placed side by side, and when the upper sides are cleaned, the pieces are turned over and the opposite sides cleaned. When cleaned, the steel is painted, and then removed and piled by the crane.

Mr. Belzner. Nozzles of extra-heavy, ½-in. gas pipe, varying from 7 to 18 ins. in length, have been used; but it has been found that the 12-in. lengths are most effective. The life of the nozzles varied with the sharpness of the sand, the temper of the pipe material, and the air pressure, but, on the average, lasted 1½ hours. The nozzles were generally worn through, about 2 to 3 ins. from the reducer, owing to the deflection of the sand leaving the large hose, passing through the reducer and then striking the nozzle at that point. This condition would suggest that a special, graduated coupling from hose to reducer be devised, so that the sand would pass through at a uniform rate without meeting a break, thus avoiding the deflection.

The force consists of a foreman, who regulates the valves controlling air and sand, two nozzle-men who direct the blast (these men had to wear goggles to protect their eyes), two men to dry the sand, attend to the fire and keep the tanks filled, and also, one laborer, who assists the nozzle-men in handling the hose.

As the yard covered a large area and the steel was distributed all over it, it was a question whether it would be more economical to have a portable blasting machine or to make it stationary and use the crane and traveler for the purpose of handling materials. It was finally decided to make the plant stationary and use the crane for collecting and subsequently piling the steel.

The material cleaned consists principally of bulb angle-columns, I-beams for wall-columns, roof I-beams, knee-braces, rivets, plate girders, splice-plates, grillage-beams, and angles. Plate XXVIII shows a girder before and after being cleaned by the sand-blast.

The question of the advisability of cleaning the steel before it leaves the shops could well be taken up. Were the mill scale and dirt removed before the steel is painted, the protective coating given it at the shops would undoubtedly prove more effective in the prevention of corrosion than by the present methods.

Such an adjunct to the manufacturing plants, if properly laid out, could resolve itself into practically first cost. If automatic devices for drying the sand and then feeding it to the blast were devised, much labor and time would be saved. Still more, the nozzles of the blast could be in a fixed position, and a rolling table provided for the steel. An automatic device for spraying the paint on the steel might also prove an advantage.

In preparing this discussion the speaker had the assistance of Mr. R. S. Fowler, Junior Assistant Resident Engineer, who also furnished the data, photographs and drawings. The speaker's thanks are also due to Mr. J. J. Shannon, Inspector for the Rapid Transit Subway Construction Company, for useful suggestions.

Mr. Paschke. Theodore Paschke, M. Am. Soc. C. E.—Before giving any figures which can serve as a basis for comparison with those given by Mr.

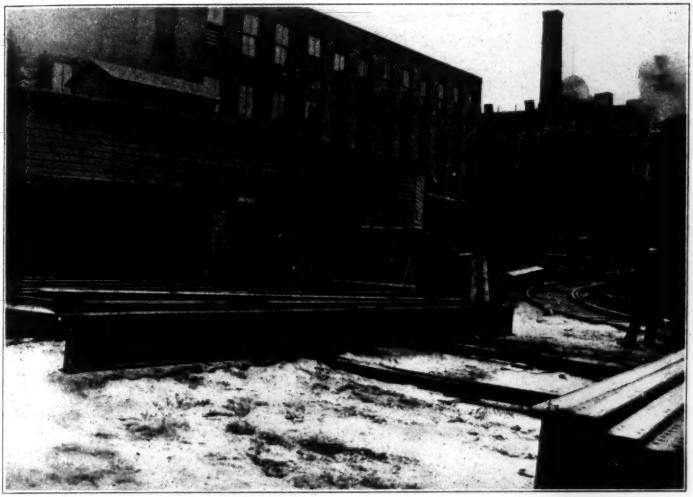


FIG. 1.—FIFTEEN INCH I-BEAM, BEFORE BEING CLEANED WITH THE SAND-BLAST.

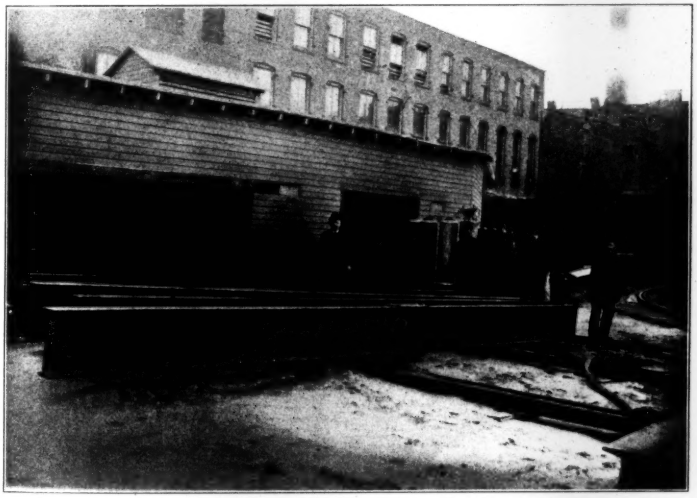


FIG. 2.—FIFTEEN-INCH I-BEAM, AFTER BEING CLEANED WITH THE SAND-BLAST.

Lilly, as to the cost of cleaning some of the structural steel for the New York Rapid Transit Subway, as described by Mr. Belzner, it will be necessary to state briefly and as nearly as possible the actual conditions, rather adverse in some cases, under which the work had to be done. Mr. Paschke.

When it became evident that the shop coat of paint had been practically destroyed by long exposure, and that it was necessary to arrest the destructive work of corrosion which had set in, the Subway Construction Company, in obedience to orders from the Rapid Transit Commission, assumed the responsibility of the work, and arranged with its sub-contractors on Sections Nos. 2 and 3 to perform the work of cleaning the steel and replacing the shop coat of paint, as an extra, at cost plus the percentage allowance customary in such cases.

The sub-contractors for Section No. 2 (comprising the Elm Street section) are the Degnon-McLean Contracting Company; for Section No. 3 (comprising Lafayette Place and Fourth Avenue) the Holbrook, Cabot and Daly Contracting Company. The work was done by them subject to the inspection of the engineers of the Rapid Transit Commission.

The work was started by hand cleaning, that is, by hammer, scraper and wire-brush. This did not prove satisfactory either in point of cost or in efficiency, and involved the sub-contractors in an almost continuous controversy with the inspectors. It was suggested that the sand-blast process be used, and in view of the fact that the sub-contractors had compressed-air pipes along the line of their work, thus facilitating the installation of such process, Mr. Deyo, Chief Engineer of the Subway Construction Company, readily assented.

On the Elm Street section the steel to be cleaned was piled at various points along the street. Mr. Belzner has described the attempts made to locate the sand-blast at the various piles of steel. Thus, the operation of the blast had to be confined to one point and carried on during night hours. The steel had to be brought to the sand-blast, and there manipulated by hand entirely. The arrangements for drying the sand were primitive, owing to the temporary conditions of the work. The first cost of installation of the blasts, their various removals and transfers from one point to another, was added to the cost, tending to increase this abnormally.

At the Forty-second Street yard, where the Fourth Avenue steel was piled, the conditions were somewhat different. The yard is 200 ft. wide and 700 ft. long, and is provided with a network of tracks and a traveling crane with a flat car for the handling of the steel. Here, a plant on a little more permanent basis was erected, and the steel handled and brought to it from the various points of the yard by the traveling crane. Although these conditions were more favorable than on Elm Street, they may be considered rather exceptional for such work.

Mr. Paschke. In the work on Elm Street and at the Forty-second Street yard about 5 000 tons of steel have been cleaned by this process.

But all this steel was not cleaned over its entire surface; only about one-half being cleaned entirely, one-quarter had 75% of its surface cleaned, and on the other quarter about 50% of its surface underwent the sand-blast process, for the reason that on the remaining surface the shop coat was found to be in good condition.

In the case of the work at the Forty-second Street yard, the total cost, including the repainting, amounted to from $3.50 to $6.50 per ton, the higher cost being due to the greater adversities experienced during the winter months. In the case of the work done on Elm Street, the cost ranged about $1.50 per ton higher. It should be stated that the eight-hour basis for a day's work is in vogue throughout the subway, and that the entire work of cleaning and painting had to be conducted in the open, exposed to all the vicissitudes of the weather, resulting often in the necessity of reblasting the steel, before being able to paint it.

It would seem from these figures that in the case under consideration the use of the sand-blast did not result in any direct economy over hand cleaning. However, the results obtained were infinitely superior. The steel, after emerging from the sand-blast, presented a beautiful appearance, in fact, being fit to go into an electro-plating bath.

The experience had here with the usual customary shop coat as a protection for the steel against corrosion before erection seems to confirm Mr. Lilly's contention for the desirability of applying the sand-blast to structural steel at the works, after manufacture and before the application of the shop coat. Notwithstanding the high cost of the work performed in the present instance, which was due to exceptional and rather abnormal conditions, the speaker fully believes that the sand-blast process can be used at the works to advantage, and at a cost not exceeding that given by Mr. Lilly.

Mr. Sabin. A. H. SABIN, Assoc. M. Soc. C. E.—Although the speaker has never actually conducted any sand-blast work, he believes that it was at his suggestion that the sand-blast was used upon the One Hundred and Fifty-fifth Street Viaduct some years ago. He has, however, been interested for years in this matter of the proper cleaning of structural steel before painting, and can agree fully with what Mr. Lilly says about its great importance. It is a waste of money to buy even the best of paint and spend a large sum for labor in applying it to a rusty surface.

More than a hundred years ago, one of the great early English engineers—Smeaton—remarked that he had observed that if rust had once started on the surface of the iron, it made no difference what varnish or paint was applied to the surface, the rusting would continue

to go on progressively under the paint. That conclusion has been reached by every man who has investigated the subject honestly and disinterestedly. Mr. Sabin.

Mr. Paschke has stated that when the steel had been cleaned with the sand-blast it was fit to go into an electro-plating bath. That is right. It will be observed that it is assumed that if a piece of metal is to be electro-plated it has to be clean, down to the surface of the metal; none of the oxide or scale must be left on the surface. It is equally true that to apply a vitreous enamel, such as on granite earthenware, etc., in the first place the surface of the metal must be obtained on which to put the enamel. All such ironwork is cleaned usually by pickling. To apply a varnish enamel, as in the case of a bicycle frame, it is absolutely necessary to do the same thing; otherwise the enamel, or the electro-plate, will come off in time, because the rate of expansion of the scale is always a little different from that of the iron, and in time the scale will loosen up.

Now, the speaker is a paint man, and has had an experience of a good many years. He believes that paint sticks on iron in exactly the same way that anything else does, and the conditions which favor the adhesion of other things favor the adhesion of paint. If it is necessary, if it is absolutely indispensable, as all agree, to have all these other coatings applied to the actual surface of the metal, and not to any scale or rust, or anything of that sort, it is also desirable to apply paint directly on the iron.

There are plenty of people who think—no doubt many who think honestly—that the oil and paint will mix up with the iron rust and keep out the air, and in that way the corrosion will be stopped. The trouble with that theory is that the paint and varnish are not absolutely non-porous. If they were it would be all right. Neither is cement or concrete non-porous, and when the corrosion gets under way, its action is very rapid. That is a chemical question which is not worth while discussing now as it has been beaten over a good many times, and probably most of those who are interested in the subject are thoroughly familiar with the theory of the matter.

It is comparatively easy to keep iron free from rust when it is clean, but, after the rust has started, it is very difficult to stop it or to clean it away from the metal.

The speaker had hoped that this paper might bring out a discussion from somebody who had had experience in cleaning iron by dipping it in acids, or "pickling." Of course, that is not sand-blasting, but the result is what is desired. The speaker is not aware that, in this country, any structural metal-work has been cleaned by pickling, but a great deal has been cleaned in Europe, some of it many years ago, and it is being done now, with most excellent results. Of course, the result of a first-class job of pickling is just the same as the result of sand-blasting.

Mr. Sabin. One of the advantages of the sand-blast, not mentioned by Mr. Lilly, is that it leaves the iron not only clean, but dry. The process of pickling leaves the surface of the iron wet, and it has to be dried. It would be difficult to apply the process of pickling to structural work in place, such as an erected bridge, or anything of that sort, but it would have been extremely interesting to have had an idea of the comparative cost of cleaning the steel for the Rapid Transit work by pickling, as compared with the sand-blast.

There is probably a thousand times as much iron and steel cleaned by pickling as is cleaned by the sand-blast. There is an immense amount of it done. Those who are not familiar with the subject have no idea of the extent to which it is practiced, but, in this country, it has not been applied to structural steel.

There is a feature which did not appear in Mr. Snow's admirable discussion. Mr. Snow has really had a great deal of experience in the use of the sand-blast on bridges, and has told the speaker that, usually, he did not clean the whole of a bridge with the sand-blast, as that is regarded as rather expensive. Such parts of the bridge as are specially liable to corrosion are cleaned by the sand-blast, and other portions, which are not so subject to deterioration, are cleaned in a less thorough and less expensive manner, for the reason that those portions which are most liable to corrosion will, in spite of the greatest care that can be taken, probably rust out as rapidly as the other portions with somewhat less care, although, of course, a man who is sufficiently interested in the matter to do sand-blasting is not going to have any poor work done. This feature, however, is worth remembering.

It may be regarded in another way. If a man sets up a sand-blast plant to clean a bridge, and has all his apparatus and his gang of men to do it, and only cleans, say, one-quarter or one-third of the bridge, he cannot do that quarter or third of the bridge as cheaply per square foot as he could clean the whole bridge, so that the cost per square foot is a great deal higher than it would be if he were cleaning the whole work, and for that reason any figures that he gets must be taken with regard to that fact.

In reference to the possible danger of cutting away the iron: Mr. Lilly observed that it was immensely more difficult, and required a great deal more power, to remove a hard compact scale than to remove ordinary rust. Now, the difficulty of cutting away tough, hard steel is immensely greater than that of cutting away the hardest kind of rust, and the speaker was told—this was not his own experience—by the manager of the Wolff Bicycle Company, some years ago, when they were using the sand-blast for cleaning the frames of bicycles, that before they purchased their sand-blast apparatus, they were apprehensive about cutting away the metal, because the tubing they used

was very thin; and to test the matter they held a piece of tubing in the current from the sand-blast machine for twenty minutes continuously and then, with a micrometer scale caliper, which would show a thousandth of an inch, were not able to find any diminution in the diameter of the tube. Consequently, they thought that they were safe in using it; and if that is the case, there should not be very much apprehension as to cutting away the steel. Mr. Sabin.

H. B. SEAMAN, M. Am. Soc. C. E.—There seems to be little to add to the discussion which has already taken place, except, possibly, to mention the dangers of the misuse of the sand-blast. It is undoubtedly a most efficient method of cleaning iron, especially where the rust is badly caked, or is in inaccessible corners and cannot be reached by hand; but where the rust is light, and especially where surrounded by elastic paint, the excessive use of the sand-blast may prove more injurious than the rust which it removes. The sand-blast will remove the rust quickly, but if continued long enough to remove the elastic paint, which requires considerably more time, the parts which were rusted will be worn deep and pitted, and when the whole surface is bright and smooth, and acceptable to an enthusiastic inspector, more metallic iron may have been removed than would be the case after several ordinary coats of rust. Furthermore, the naked iron, as left by the sand-blast, will rust much more quickly than when the mill finish is left. Mr. Seaman.

An illustration of the danger of overdoing the sand-blast occurred recently, under the supervision of an ardent, but well-meaning, inspector. Four columns, which had been similarly exposed to the weather while stored in the same pile awaiting erection, were brought out and laid side by side to be cleaned by the sand-blast. After 3½ hours of the sand-blast two of these columns were stripped absolutely clean of rust and paint, and of all sign of the original mill surface; finished, in fact, clean enough for electro-plating. The work could not have been done more thoroughly if performed in a laboratory for experimental purposes. The remaining two columns were then cleaned of rust and dirt, but all good paint was left on. This required 45 minutes, and the columns were left in better condition than the first two, at about one-fourth of the expense.

The theory that iron must be cleaned to a white surface before being painted does not seem tenable. The thin coat of black oxide formed after rolling is of itself a valuable protection, being the most permanent form of iron oxide, and even when the iron is tinted brown with rust it is not clear why the paint which would protect the iron from rusting, will not in like manner prevent the rust from progressing, excepting, of course, where the rust is so thick as to prevent adhesion of the paint to the iron. Where the sand-blast is used it is necessary to paint at once to prevent corrosion.

Aside from the commercial or scientific value of sand-blasting, there

Mr. Seaman. is a very serious question of its effect upon the eyes and lungs of the operator. Its use in connection with bridge shops would seem, not only objectionable on account of its disturbing effect upon the other operations, but, as already mentioned, would remove the black oxide of manufacture, which is its natural protection. Any scale which may be formed after rolling is quite thoroughly removed in punching and handling through the shops.

Mr. Tays. E. A. H. TAYS, M. Am. Soc. C. E. (by letter).—The writer has noticed that the means of drying the sand, as described by Mr. Lilly, were very crude, and the idea suggested itself that they could be improved.

The following suggestions may be of service in enabling those of the profession engaged in that work to improve upon the present practice in that line.

Where temporary plants are required, a sheet-iron bed, 8 ft. long, 4 ft. wide, or wider, made hollow, about 4 ins. high, or, with sufficient room for a 2-in. steam coil, or line of pipes, set on a frame 3 ft. high, would do the work; the steam coil being used to pass the exhaust steam through; or, the exhaust could be turned directly into the hollow bed. This bed can be made of the thinnest sheet or galvanized-iron, and should have a 2-in. flange on the sides, but none at the ends; and it might be set with a slight fall, to facilitate drawing off the sand with a hoe or rake at the lower end.

In large, stationary plants, a cylindrical dryer, on the lines of the Howell-White roaster, or of the type of the ordinary ore-dryer used in dry-crushing mills, would seem to be just about the thing. It could be made of much lighter material than the ore-dryer and much smaller in size.

This dryer is a revolving cylinder, larger at one end than at the other, and is heated by wood or coal, the heat passing down the cylinder. The sand is fed into a hopper at the small end, and the revolutions of the cylinder, say five per minute, gradually pass it out at the other, thoroughly dried.

These observations may enable some of those who are working in this line to devise an economical as well as efficient sand-dryer; if so, the object of these remarks will have been attained.

Mr. Lilly. GEORGE W. LILLY, Assoc. M. Am. Soc. C. E. (by letter).—Mr. A. H. Sabin has called attention to the fact that one of the great advantages of the use of the sand-blast is the dry condition of the metal after being cleaned by it. This is certainly a great advantage and essential to the best efficiency of the preservative paint. It is also true that, unless the paint is applied soon after the cleaning is done, moisture is likely to accumulate on the steel, especially if the atmosphere is nearly or quite saturated with moisture. It has been urged, therefore, that the paint should be spread within the shortest possible time after the

cleaning is done, and in no case should any cleaned surface be permitted to remain over night without a coat of paint upon it. Some delay, say 2 or 3 hours, may be permitted when the atmosphere has only slight humidity. When the atmosphere is surcharged with humidity the moisture may gather on the steel immediately after it is cleaned. At such times no cleaning or painting should be done. Mr. Lilly.

While, as Mr. Snow says, it may be considered no disadvantage to have some sand get into the raw paint, if it is to be subjected to the blast action of locomotives; yet screens are sometimes of advantage to prevent too large a quantity of sand getting into the paint in the buckets before it is applied to the steel. At times the wind may send large quantities of sand back to the painters and the paint become so filled with sand that it rolls under the brush and cannot be spread properly. It is not often found necessary, however, to use the screens between the nozzle-men and the painters.

The writer admits freely that neither the pan nor the hopper form of sand-dryer is scientific or highly efficient. A rotary dryer is, no doubt, a good form, where power is available and the exhaust steam may be utilized; but, at Columbus, Ohio, the power was from 1 200 to 2 100 ft. from the places where the cleaning was done. No doubt, a better sand-dryer can be devised than any of those which have been used in the work done heretofore.

Mr. Seaman urges caution against the danger of extending the use of the sand-blast too far and cleaning steel which is already in good condition to receive the paint. The same thought was suggested in the paper, and it is certainly true that good judgment should be exercised. The intelligent application of the process, in the cases where it is required to prepare the surface of the metal so that the paint, when applied, will adhere properly and give good protection against further corrosion, is all that is contended for. For the reason that some of the paint was still good, some parts of the viaducts named in the paper were not sand-blasted down to the metal surface, but rust spots only were cleaned away. The parts where rust and corrosion have destroyed the paint, and where the paint is dead and disintegrating, should be cleaned thoroughly; and the sand-blast seems to be the best process for such purpose.

The black or magnetic oxide spoken of by Mr. Seaman is nearly all destroyed by the rusting of the metal before the shop work is completed, save, perhaps, where the thicker scale has formed. That all the mill scale is removed by the processes through which the steel passes in the shop is, the writer believes, putting the case rather too strongly.

Mr. Fowler suggests permitting the metal to rust somewhat, in order to remove scale as far as possible, and then cleaning it thoroughly before painting. It will be observed, if a careful examination of old

Mr. Lilly. structures be made, that in many cases the mill scale has been covered with paint, and corrosion has attacked the steel and loosened the scale, making centers from which rust will extend.

The composition of mill scale, or, at least, of its characteristic, porous inner layer, makes it reasonable to expect just such results. Mill scale forms in two layers, the inner one being represented approximately by the formula $6\,Fe\,O + Fe_2\,O_3$, and, as stated, is very porous and brittle. The outer layer contains a larger but varying proportion of $Fe_2\,O_3$. The air and moisture contained in this porous scale tend to destroy the paint spread over it by starting corrosion. This scale is magnetic. A galvanic action is said to be set up around the edges, and corrosion commences there and afterward extends under the scale and outward under the paint. It is considered important, therefore, that the mill scale be removed by some efficient means before the first coat of paint is applied.

The difficulty in getting the moisture to pass off when drying the sand has been overcome, to a great extent, this season, by inserting, in a vertical position, in the hopper of the dryer, a number of pieces of galvanized iron pipe, punched full of holes, to admit the steam and let it pass up and escape through them. They act as flues, and the sand dries more rapidly than in a hopper such as shown in Fig. 1, of Plate XXVII.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 949.

THE PRESERVATION OF MATERIALS OF CONSTRUCTION.

AN INFORMAL DISCUSSION PRESENTED AT THE MEETING OF FEBRUARY 4TH, 1903.

BY MESSRS. WILLIAM BARCLAY PARSONS, JAMES FORGIE, WILLIAM R. WEBSTER, RUDOLPH P. MILLER, GEORGE HILL, OSCAR LOWINSON, HENRY B. SEAMAN, GEORGE A. JUST, A. GIDEON, FRANKLIN RIFFLE, EDWARD P. NORTH, HORACE J. HOWE, THEODORE BELZNER, WILLIAM W. CREHORE AND W. W. KENLY.

Mr. Parsons.

WILLIAM BARCLAY PARSONS, M. Am. Soc. C. E.—Engineers are accustomed to put into structures materials which are expected to remain unimpaired for a great many years, but they are obliged to take a great deal on faith; therefore it is especially interesting to examine any material whose age can be thoroughly authenticated, and whose state of soundness or decay can be ascertained accurately.

Last autumn, while inspecting the subway construction of the Metropolitan Railway in Paris, the speaker was shown some timbers which had formed part of the foundations of an old building erected in the fourteenth century; and the chief engineer, Mr. M. F. Bienvenue, has very kindly sent some pieces of the piles and the timber grillage, which now, on his behalf, and in his name, the speaker takes great pleasure in presenting to the Society.

The following is a translation of the letter accompanying these specimens:

On October 5th, 1902, while excavating the trenches under the Place de la République, for that part of the Chemin de Fer Metropolitain between Courcelles and Menilmontant, there was discovered a great quantity of oak piling supporting an oak platform.

Mr. Parsons.

The piles were from 1.50 to 2.00 m. in length, and from 20 to 25 cm. in diameter. The lower part of each was sharpened to a square point, but bore no traces of iron banding or of crushing. The width of the platform timbers varied from 50 to 70 cm., and their thickness from 10 to 15 cm.

This wood, which was a true pile foundation, has been identified as composing part of the foundations of the old "Porte du Temple," having formed part of the wall of Paris during the reign of Charles V (1364–1380). The preservation of the wood is perfect, notwithstanding the fact that it has been in place since the fourteenth century.

The lower part of the piles was embedded in a green argillaceous sand, while the upper part was in a blackish, marshy soil, filled with sulphurous and ammoniacal gases.

The lower part of the platform was about at elevation 29.00 at the point where it was uncovered, the elevation of the surface of the ground at the Place de la République being about 37.00.*

On top of the specimen of the pile may be seen fragments of the cement or lime probably used to level out under the grillage. When the wood was received, a few weeks ago, it was intact, but, by lying in the speaker's office, the heat has produced certain checks and cracks. The pile is in a perfect state of preservation, the wood is soft—not hardened at all—and resembles a piece of wood which has been in the ground but a short time.

The two specimens of the grillage on top of the piles are also checked, owing to the office heat, but, on both pieces—the larger piece especially—remnants of the bark may be seen, showing that even the bark is still intact.

It is interesting to recall that these pieces of wood were put in the ground at a period before the discovery of America equal in length to that period which has elapsed since the Declaration of Independence.

As indicative of the fact, however, that French soil is not the only kind which will preserve wood, sections of the first water pipes laid in the City of New York, by Aaron Burr's Company, about the year 1800, have been found recently in Centre Street and the adjoining streets, by the contractors for the Rapid Transit Commissioners. These are not as old as the French wood, but, nevertheless, they are sufficiently venerable, as they have now passed into their second century. Some of the pipes are quite decayed where they have been buried in dry sand, but where there has been moisture in the sand, the wood is still sound.

†The preservative effect of cement mortar on steel has been noticed by the speaker in the case of some steel beams taken out of the sidewalk vault of a building on Fourth Avenue, in New York City.

*The original letter of Mr. Bienvenue, together with the samples of wood, and a plan of the exact location of the old foundation, are on file in the Library.

†This part of Mr. Parsons' discussion added after hearing discussions by Messrs. Forgie, Miller and Hill.

Mr. Parsons.

These beams were put in place in 1880 or 1881, so that they are now about twenty-two years old. They carried brick arches for most of their length, but the outer or curb ends were embedded in rubble masonry.

Above the jack arches a space of 2 or 3 ins. was filled with ashes, on top of which the sidewalk was laid.

The beams are in very good condition, except at the ends near the curb, and where the rubble masonry had been cracked by the impact of wheels against the curb, thus permitting water to percolate and attack the steel.

On comparing the part which had been embedded in the masonry with that part which had carried the arches, it was noted that the latter, although it had never been painted, was practically free from rust.

The speaker would like to ask the members to give their opinions as to whether steel should be painted before being embedded in masonry, or whether it is better to let the cement come into direct contact with the fresh metal. This is an important question, because a great deal of steel is now being embedded in concrete.

Mr. Forgie.

JAMES FORGIE, M. Inst. C. E. (by letter).—Quite recently, and incidentally, the writer mentioned to Mr. Noble that he had a piece of iron, about 200 years old, in the form of a masonry cramp or bonding iron, approximately $\frac{3}{8} \times \frac{3}{4} \times 6\frac{1}{2}$ ins., with the addition of the ends turned down (Fig. 1), and which he thought might be worthy of testing, both physically and chemically.

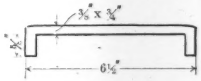


FIG. 1.

Mr. C. L. Harrison has suggested that, in view of the discussion on "The Preservation of Materials of Construction," a note of the history of this piece of iron might be presented, and, probably, in view of the gigantic iron-framed buildings, where the iron is largely inaccessible for painting, it may be of all the more interest to American engineers.

In 1899, while acting for Sir Benjamin Baker and Messrs. Hay and Mott as Chief Assistant Engineer on the City and South London Deep Underground Railways, the writer found this piece of iron within the sandstone masonry of one of four piers forming the pedestals of four triple sets of stone Corinthian columns which were being underpinned to steel girders, in the process of forming a railroad depot in the crypt or vaults of St. Mary Woolnoth Church, at the junction of Lombard and King William Streets, facing the Bank of England, in London, England.

From this pier also radiated the vaulting or arch groining forming the floor of the church and the roof of the crypt, where, also, several human bodies were found encased in complete lead-shell coffins embedded in the foundations.

Mr. Forgie. This church was built on the site of a church destroyed previously by the great fire of London in 1666, and was designed by Nicholas Hawksmoor, a pupil, and eventually a contemporary, of Sir Christopher Wren.

The iron cramp or bond was wholly embedded in a horizontal sandstone masonry joint made of lime (a hydraulic and not a pure lime).

It may be observed that practically no oxidation can be discerned by the microscope. Attention is also drawn to the pieces of lime still clinging to the iron.

It may be that the lime has acted as a preservative, and, *a propos* of this, the writer may be permitted to observe that in 1895 a piece, about 12 ins. square, of the cast-iron shell of the Tower Subway under the Thames, built in 1869–70, was cut out for the inspection of the Arbitrator in the City of London *versus* the Subway Company. The writer saw this piece immediately after it was cut out, and, on removing the shell of lias (hydraulic) lime grout from the iron, the thin coating of coal tar, which still remained on the iron, smelt perfectly fresh, and the iron was in perfect condition. Within the past six or seven years the writer has removed several hundred feet of other cast-iron tunnels in the process of enlarging the Subway. These had been in place from ten to twelve years, and the iron was also found to be in a perfect state of preservation. The soil in which these tunnels are built is a stiff blue moist clay.

On account of the strong belief in hydraulic lime and Portland cement as a preservative of iron, all the 400 to 500 tons of steel columns and girders which now carry the afore-mentioned church, over the railway depot, were covered with expanded metal and then wholly encased in neat Portland cement.

Fig. 1, Plate XXIX, is a photograph, of the partially demolished vaulting of the church, on which the place from which the iron cramp was taken is indicated by a cross. Fig. 2, Plate XXIX, is a photograph of the cramp.

Mr. Webster. William R. Webster, M. Am. Soc. C. E. (by letter).—The small iron cramp referred to by Mr. Forgie, which was subsequently sent to the writer for test, seems to have been originally $\frac{3}{4} \times \frac{3}{8}$ in., one end thickened in bending and the other end considerably wasted away.

Before testing the cramp the ends were sawn off, leaving them in their original condition. The material was very hard in spots, and three hack-saws were dulled in cutting off the ends. The body of the cramp was cleaned of all scale and mortar by light blows of a hammer. It was rusted badly in some places under the adhering mortar. In order to grip it in the testing machine it had to be reduced in thickness, and on pulling developed a bad seam, otherwise the ultimate strength would, no doubt, have been somewhat higher. The following are the results obtained:

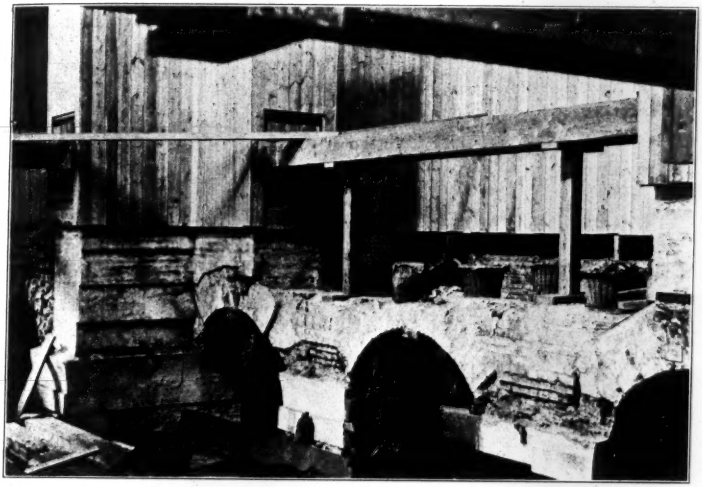


FIG. 1.—PARTIALLY DEMOLISHED CRYPT OF ST. MARY WOOLNOTH CHURCH. THE CROSS INDICATES THE PLACE FROM WHICH THE IRON CRAMP WAS TAKEN.

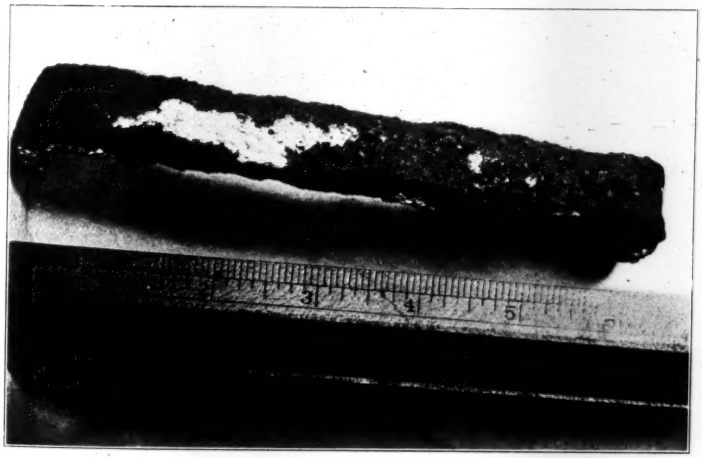


FIG. 2.—IRON CRAMP TAKEN FROM MASONRY IN CRYPT OF ST. MARY WOOLNOTH CHURCH, LONDON, ENGLAND.

Mr. Webster.

Area.	Ultimate strength.	Percentage of elongation in 2 ins.	Percentage of reduction.
0.104 in.....	51 226 lbs.	18.00	35.3

Analysis.—Carbon, 0.008%; sulphur, 0.027%; phosphorus, 0.060 per cent.

The writer is indebted to Mr. R. Job, Chemist of the Philadelphia and Reading Railroad Company, for the chemical determinations.

Mr. Miller.

RUDOLPH P. MILLER, Assoc. M. Am. Soc. C. E.—Considerable interest has been aroused by the demolition of a modern steel-skeleton building in New York City. Many varying expressions as to what would be revealed when the steelwork should be exposed, especially as to its state of preservation, led the Superintendent of Buildings for the Borough of Manhattan to have the building examined carefully during its demolition. Photographs and notes have been taken since the work of demolition started, about six weeks ago. The building has not yet been taken down completely, and a full report on the matter is not yet prepared. The photographs, unfortunately, do not show the condition of the material, it being difficult and practically impossible to distinguish on the pictures between rust and discolorations due to the adhesion of particles of the fire-proof coverings, yet they can serve conveniently the purpose of illustrating some of the facts to be noted.

The building was situated on the north side of Forty-second Street, running from Broadway to Seventh Avenue, and was known, variously, as the Thorley Building and the Pabst Building.

It was erected about four years ago, having been started in October, 1898, and completed about a year later.

The steelwork was put in during the months of December, January, February and March. The structure was about 25 ft. deep, of an average length of about 54 ft., and was nine stories high, or about 108 ft. The foundations were on rock.

The construction consisted of a frame of Z-bar columns, with beams and girders carrying the floors and walls at each story. The walls were of brick, except those of the second story, which were of limestone, the first story having an iron front.

The steelwork, when delivered at the site, had received one coat of carbon paint. It was put up as fast as delivered, and was followed very quickly by the masonry. In some portions of the work the masons were so close behind the erectors that part of the framework probably never received a second coat of paint.

It is interesting to note that the steelwork in the fourth, fifth and sixth stories showed more rust than that in the stories either above or below.

Mr. Miller. The interior columns, for the most part, were enclosed in hollow terra cotta blocks, but by no means always solidly. Along the webs of the Z-bars, at right angles to the web of the columns, the contact between the steel and the fire-proof covering was generally complete. On the other sides of the columns, however, the terra cotta blocks were often placed spanning the space between the Z-bars, leaving a void between the fire-proofing and the main web of the column. The steelwork was in equally good condition on all sides of the columns. These columns showed little patches of rust here and there, but none that could not be explained by some cause at work before the steel was put in place. For instance, the rust may have set in under the mill scale before the columns were painted or set, not being visible from the outside, as the mill scale is a non-corrosive oxide of iron. There was in no case a general or extended rusting of any steel member. The points where rust showed in the columns most generally were the rivet heads and the connections.

The connections were the parts most affected by rust. The worst example of corrosion in the building, thus far, is illustrated in Fig 1, Plate XXX. In this case, practically the entire inside of the splice plates, where they show black on the photograph, was rusted, and the faces of the connections that were in contact were rusted. The speaker has no doubt that, in setting one column above another, considerable force was used, and the friction between the parts was sufficient to rub off the shop coat of paint. The heads of the field rivets were the places where rust was oftenest found, yet in no case, except in that illustrated, was the rust of a thickness that could be measured by ordinary means. In this case the thickness was from 0.02 to 0.025 in.

The wall columns were encased in brickwork, 8 ins. thick on the outside and 4 ins. thick on the inside, the inside 4 ins. being what is known as furring bricks. In some of these columns there were indications of rust in layers, as shown in Fig. 2, Plate XXX. The steel was free from rust where the cement mortar came in contact with it, but between such points it appears as though the porous brick permitted the entrance of sufficient moisture to start rust; but, again, in no measurable quantity. This is in accord with observations made in a number of other instances where alterations in a building have exposed steel columns.

The floor beams and girders throughout the interior of the building, except the top flanges, were encased in the cinder concrete forming the floor arches of the building. The concrete was made up in the ordinary proportions for that form of construction (that is, 1 part cement, 2 parts sand and 5 parts cinders), and was a fair sample of cinder concrete as generally used in building construction in New York City. Yet the steelwork thus protected was remarkably free from rust. Where there was any, it was in very small patches, more

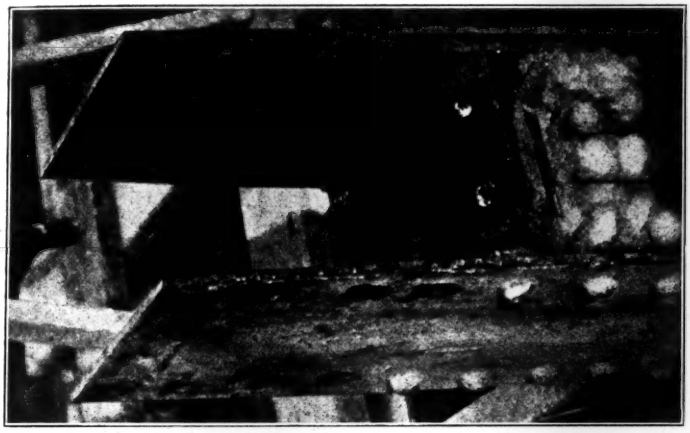


FIG. 1.—CORRODED SPLICE PLATES.

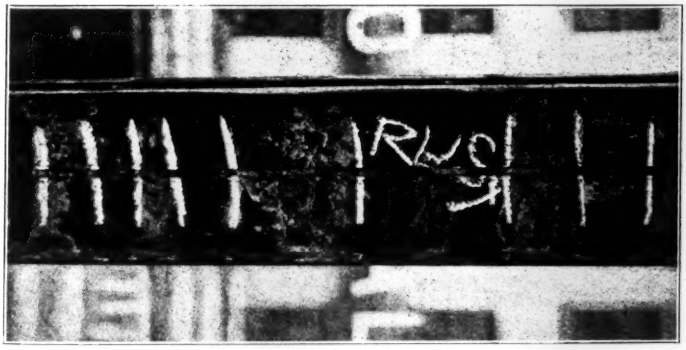


FIG. 2.—RUST SHOWING ON STEELWORK WHERE CEMENT WAS NOT IN CONTACT WITH STEEL.

generally on the rivet heads, and it was probably there before the floor arches were placed. Mr. Miller.

Practically, the only place where any rust was shown was on the webs of the channels forming the frame for the stair-well and elevator shaft, and then it was on the shaft side, where it was not covered with some protective material other than paint.

The wall girders, encased in brickwork on the outside, showed signs of rust along the edges of the flanges toward the outside of the building. This was more especially true of those in the northerly wall, which, for most of its height, was exposed to the weather. The adjoining building to the north was of four stories. The flanges of these wall girders came within about 2 or 3 ins. of the outside of the wall of the building.

A built-up girder, in the westerly wall, at the second-story floor level, shows two patches of rust on the web of the girder. No explanation has been found for these patches of rust, which are exceptional. The sides of the girders were thoroughly encased. It may be remarked that the present indications are that the steelwork yet to be removed from this building, in the basement and cellar stories, will show considerably more rust than any taken out of the upper part of the building. It should be noted that the steelwork was erected during very bad weather, and the location was a particularly damp one. On one or two occasions the work had to be stopped on account of snow storms or rain.

The concrete of the floor filling was segmental in form, and was supported by temporary centering, consisting of $\frac{1}{2}$-in. round bars spaced about 9 ins. apart, which stiffened the wire netting. This centering was rusted throughout the building—generally, however, only on the side exposed—and the rust is not more than would develop during the drying out of such a floor construction. This floor was hidden and covered over by a flat ceiling, secured to the lower flanges of the beams. The rusting evidently did not continue after the floors had dried out and the ceiling had been put in place.

The boiler stack of the building was of $\frac{5}{16}$ and $\frac{1}{4}$-in. sheet-steel, and was covered with asbestos.

The stack was completely covered with rust, the asbestos covering evidently offering no protection, although the galvanized wire woven into the asbestos covering was as bright as the day it was put in.

The expanded metal used in the partitions was very badly rusted throughout the building. This may have been rusted when put in, for such material is generally sent to a job in bundles, and lies about, exposed to the weather, for some time before being put in place; but the material of the partitions, which was a patent plaster, evidently did not arrest the corrosion, but probably increased it.

One 6-in. floor beam, shown in Fig. 1, Plate XXXI, was rusted badly

Mr. Miller. for an area of, perhaps, 1 sq. ft.; but all the indications are that this beam, over this particular spot, was never painted. Evidently, the beam was marked at this place at the mills before being painted, and, when painted, this spot was not touched, in order not to obliterate the marks.

All steelwork erected in New York City is supposed to receive a coat of paint after being set, but this is not always done, for several reasons—sometimes to save the expense, which the speaker is sure was not the case in this instance; often because of the untrustworthiness of the workmen, who shirk those parts which are difficult of access; again, when the masons are following close behind the steel erectors, they will not wait for the painting. The tops of beams and girders do not often get the second coat of paint because the erectors, in climbing over the steelwork, are more likely to slip on the freshly painted surfaces. Fresh paint in the connections is likely to spurt out during riveting, and therefore connections are often neglected.

To show how the beams come to the site unpainted sometimes, a photograph of some steelwork delivered for a new building in New York City is shown in Fig. 2, Plate XXXI.

Where the shop marks are placed on the beams, they have not been painted over at all, and, in this instance, the beams have already rusted at such places. The same beams also show indications of rust along the connections, as indicated by the chalk marks—not much, to be sure—but whether or not this incipient corrosion will continue is an open question. It is very doubtful that the rust will be scraped off before the next coat of paint is put on, and if not, it is doubtful whether the paint will be of much use. It is difficult, too, to follow the painting during erection. To meet this difficulty, some architects specify that the steel shall be painted with red lead before delivery, and with carbon paint during construction. They can then tell by the color whether or not the second coat is complete. All unpainted steel that came out of this building, whether enclosed or not, was rusted.

The speaker has been describing the places where rust was found, but it should be stated that the quantity of rust in this building was small. Most of the cases were found in the fourth and fifth stories, where the rust spots were most frequent. The steel frame, generally, was remarkably clean and free from rust. The conclusions to which these studies lead simply corroborate those of which engineers have already felt fully convinced—that paint, applied properly, is a protection to steel, at least for a certain time; that cement mortar is a very efficient protection for steel, and that ordinary cinder concrete also serves this purpose quite satisfactorily.

*Since the presentation of the notes on the demolition of the Pabst Building in New York City and the condition of the steelwork in that

*This part of Mr. Miller's discussion was added subsequently.

FIG. 1.—SIX-INCH FLOOR BEAM.

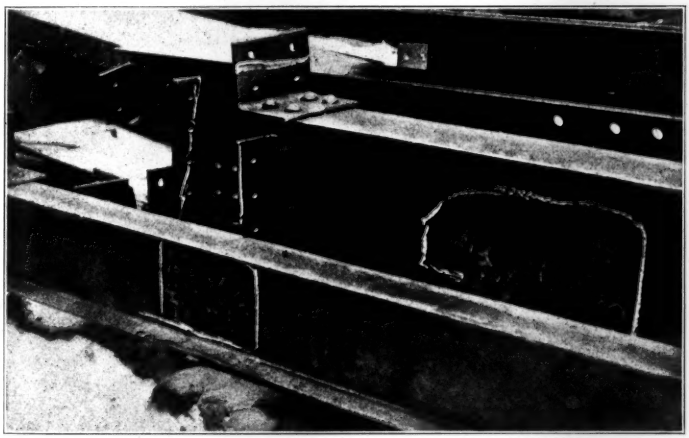


FIG. 2.—STEELWORK; PAINTED, EXCEPT WHERE SHOP MARKS ARE SHOWN.

building, a complete report on the matter has been made to the Bureau of Buildings. Mr. Miller.

As was expected at the time of the discussion, the steelwork in the basement and sub-basement of that building showed more corrosion than the upper parts. The columns supporting the sidewalk were all of cast iron, and they were in a better state of preservation than the steel columns under the building. In fact, the cast-iron columns were in a very good state of preservation, although the girders and beams adjacent to them were rusted badly in some instances. These cast-iron columns were enclosed with a galvanized-wire lath, and plastered with ordinary lime mortar, which was intended as a protection against fire. All the steel grillage-beams under the columns of the building had been coated with asphaltum, and were in a good state of preservation. The cast-iron bases which were used were enclosed with brick and cement mortar. They were clean, as far as corrosion was concerned, except on the top, where the steel columns rested on them. As a general thing, corrosion was found very commonly where two metallic surfaces came in contact.

Attention may also be called to another case, recently brought to light, in the replacing of some brick-set boilers in a New York brewery. Cast-iron columns, supporting a coal bunker above the boilers, had been built in for their lower portion in the brick setting for the boilers. This brickwork had been built about twenty-five years before, and was laid in lime mortar. The columns, for a height of about 4 ft. above the floor, were rusted to a considerable extent—in some instances, to a depth of $\frac{1}{8}$ in. The upper portions of the columns, where they were exposed, had been kept painted, and were in a good state of preservation.

George Hill, M. Am. Soc. C. E.—The speaker has thought of this subject under certain headings: Mr. Hill.

First.—The preservation of materials of construction against atmospheric deterioration, a branch which can be dismissed, because, in general, the use of such materials as will be safe against the action of frost or the elements is always attempted.

Second.—The preservation from injury due to soot or dirt from the atmosphere, a branch of the subject with which the speaker has had very little experience. Many handsome buildings are spoiled by reason of the soot, and attempts have been made, by the use of glaze on terra cotta, and by various forms of materials supposed to be impervious, or by paraffine compounds applied to the exposed surfaces, to prevent this, and it is claimed that this has been done successfully.

Third.—Protection from dampness striking through. In this particular line, the speaker has had some experience with certain walls made of patent plaster, Portland cement and sand, 2 ins. in thickness, and used as external walls of manufacturing buildings, coated

Mr. Hill. with some of the compounds which are on the market, and has found that they were efficient. He has also had experience with brick walls, coated on the inside with similar compounds, and has found that the dampness was excluded. In general, it may be said that there are certainly half a dozen different compounds, which can be obtained at a reasonable cost, which will protect buildings from deterioration through the striking in or the transmission of dampness.

Fourth.—When it comes to the preservation of metallic structures, the speaker thinks that this discussion should be in the nature of an experience meeting, and, in general, the failures rather than the successes should be described. For instance, during the last five years the speaker has erected quite a number of buildings with external curtain walls, composed of hard plaster, Portland cement and sand in equal parts, the scratch coat being applied to uncoated metallic lath, making the thickness of the scratch coat about 1 in., then a surfacing coat of Portland cement, ½ in. thick, was applied on each side, making the curtain walls a total thickness of about 2 ins. These buildings have been put up at various times, the latest one being about four years old. All are in first-class condition at present, with the exception of one.

This building is one of four, and was erected in the winter. The scratch coat was alternately frozen and thawed several times. Two years after the building was finished it was found that the outer surfacing of cement was cracking and falling off. Sheets having an area of 8 or 10 sq. ft. came off, leaving the scratch coat bare. This was left alone, and the deterioration or destruction of this wall has been going on for about two years. The entire wall now is in rather bad shape, and it is proposed to put it in good order. In every case there was a separation between the finishing coat and the scratch coat, and, in general, the wire lath, where it was on the surface of the scratch coat, or where the scratch coat came very close to the surface of the lath, was very badly rusted; but, in places, this was little more than a discoloration. In other places, the wire lath, while rusted, was probably in exactly the same condition as when the plaster was first applied to it; because sometimes several days elapsed after the bare lath was erected before it could be covered, and there is no doubt that during that time it rusted.

The adjoining building, erected in the following spring, is in absolutely perfect order to-day, and all the other buildings are in equally good condition, so that this failure was due to the alternate thawing and freezing of the scratch coat, which prevented the formation of a proper bond between it and the surfacing coat. It may be that the surfacing coat, which was of undue thickness, reaching in places as much as 1 in., was too thick, and that that was responsible for a small part of the trouble.

Fifth.—In the protection from oxidation of such a metallic structure as Mr. Miller has described, the speaker has observed a few cases where the paint on the steel has been protected with metal lath and Portland cement, and in every case has found that it afforded a sufficient protection. Mr. Hill.

In the matter of painting, although personally interested in one paint concern and very well satisfied as an individual with its product for forming a preservative coating, it is the speaker's belief that there are several paints or preservative coatings for metallic structures, to be had at the present time, which will give satisfactory surfaces when applied properly; in fact, the intelligent application of the covering in accordance with the manufacturer's directions, has almost as much to do with a satisfactory service as the composition of the paint.

Sixth.—In protection against fire the speaker had one experience which is instructive. The building was of the ordinary steel-skeleton type, and a fire occurred on the fifth floor, the heat being sufficiently intense to soften the steel steam-pipe risers, so that the deflection in some cases was as much as 6 ins. It also melted the brass air-valves on the radiators. The flames passing out of the windows melted the solder in the copper cornice, five stories above. The Fire Department was able to erect a water-tower and direct the stream from it horizontally into the building, and the fire was put out by drowning; that is, the entire floor was filled until the water flowed out over the window sills. This stream struck several of the columns, all of which were wrapped with wire lath and plastered with Portland cement and sand, with a thickness of about $\frac{3}{4}$ in., on which the white coating was applied. This covering resisted the effects of the heat and the hose stream in every case except one, where a portion of the covering, about 18 ins. long and 12 ins. wide, was torn off; but, evidently, that did not occur until the fire was practically out, because the paint on the column—the building had been erected about a year and a half—was intact and not blistered by the heat.

Some years ago the speaker made a series of experiments for the representatives of the System Mélan, using stone concrete with Portland cement surrounding T-bars of steel bent into the segment of an arch. He found that in every case, although the steel sections had been exposed to the weather for from 60 to 90 days unprotected, wherever the concrete had been in contact with the steel, no rust showed at all. The steel was not painted, and showed bright; but wherever there were voids in the concrete, due to the use of rather dry concrete with a stone aggregate, rust had set in.

In the tests made, for the expanded metal companies, in Long Island City, the slabs were generally made of very wet cinder concrete, and, during December and January, for from 30 to 45 days, were exposed to atmospheric conditions. The steel which was embedded in the cinder

Mr. Hill. concrete, or in the gravel concrete, as the case might be, was absolutely unchanged after the destruction of the slabs. A chunk of cinder concrete, in which expanded metal was embedded, and which, when it came to the speaker, was reputed to have been exposed to atmospheric conditions for five years, was kept for about a year on his window sill, where it was exposed to atmospheric conditions until the expanded metal which projected was rusted about half off. It was then split, and it was found that the expanded metal embedded in the concrete was clean and bright.

Nearly two years ago the speaker lined a very bad shaft, for the Lackawanna Railroad Company, at Scranton, Pa., with cinder concrete and expanded metal. The shaft was through quicksand, about 60 ft. to rock, and was notorious for its bad character. The wood lining put in previously had been in place about six years, and was generally rotted through. It was necessary to replace it either with wood or masonry. Expanded metal was used, with Atlas Portland cement and furnace cinders taken from the ash pile at the power-house operating the breaker in connection with the mine. The cinders were taken from this pile without any selection, and without screening. A few days ago an examination of the lining was made, and it was found to be in as good condition as when put in. The condition of the expanded metal could not be ascertained very well, but if there had been any deterioration, if the Portland cement and the cinder concrete had not been an absolute protection to the iron, the character of the water surrounding that shaft and constantly flowing through it was such that it would have eaten up every portion of the iron within a year. It is believed that under such conditions the cinder concrete acts as an absolute protection to the steel.

It seems to the speaker that it would be of great interest, and a great benefit to the Society, if the Special Committee on Uniform Tests of Cement should have its scope extended, so that an investigation could be made of the effect of neat Portland cement, Portland cement used with various aggregates and Portland cement adulterated with various lime or patent materials, in respect to the preservation of steel. The Society can certainly do very useful work along this line, and if such tests were extended to cover the use of cement in the way in which it is actually used, so that some analogy could be drawn between the test as made and the use to which the cement is put, its utility would be increased still further.

Among the practical builders in New York City, there are a good many curious notions. Some of them have told the speaker, with great seriousness, that it was very dangerous to embed a steel grillage in neat Portland cement; that the cement would burn the steel, and that this effect could be entirely overcome if a little lime were added. Others have said that it was not possible to grout a cast-iron base

with pure Portland cement, because it invariably swelled, and so on, through the whole list. Everyone who has done any work has undoubtedly heard the various peculiar notions of the "practical" men, those who have a certain amount of hand knowledge, and who do not use their heads in connection with it. Mr. Hill.

As far as the speaker's observation goes, steel which has been properly embedded in concrete remains absolutely unimpaired and perfect in its condition. The effect of painting or oiling the steel before the application of concrete does not seem to be injurious, in view of the fact that the steel cannot always be covered immediately. In the protection of relatively large sections—with the exception, perhaps, of the steel which goes into the grillages, where a most perfect covering is desirable—it would be well to give the steel one or two coats of paint; but, for the grillages, especial care should be taken to cover them thoroughly, and, in such cases, as intimate a contact as possible should be secured between the concrete and steel.

In the application of steel for the re-enforcement of concrete, the fundamental principles are that the steel should be used in small sections and of such form that it will retain its position in the mass of concrete by reason of the form rather than by reason of the adhesion between the concrete and the steel; so that a preservative coating would have only a small influence on the strength of the combination; but, as the preservative coating is expensive, and makes the steel unpleasant to handle, and as the steel can always be embedded in the concrete promptly and thus preserved from initial rusting, the speaker thinks it well that the smaller sections should not be coated.

In the mixing of concrete, the usual practice, or, at least, the practice that the speaker was taught, is wrong. It is very much easier to make concrete too dry than too wet. The concrete in the Pabst Building, described by Mr. Miller, was mixed so wet as to be really muck, and was deposited practically without tamping.

In the last few years the speaker has used a great many thousands of barrels of Portland cement in concrete, almost all of which has been deposited without tamping, and all of it so wet that the natural slope was about 30° from the horizontal. His theory of the matter is that the very fine portions of the cement are washed down in that way, and coat the steel perfectly and fully, and that the excess of water renders any extensive tamping unnecessary and thereby effects a material economy in the cost of making and depositing the concrete. The speaker's observation of a great deal of concrete deposited, usually in thin sections—sections of from 4 to 8 ins. in thickness—is that this excess of moisture does not result in a porous concrete, nor does any noticeable shrinkage result; but that, on the contrary, it saves time.

One serious danger in concrete deposited during warm weather is that of an insufficient quantity of water, and a consequent drying of

Mr. Hill. the concrete. The following experience is an illustration of this danger. Some twelve years ago, when the speaker was designing engineer for a firm of architects, it was decided that a certain windmill tower, with a heavy stone base, should contain a steel tank 50 ft. high and 14 ft. in diameter, the stone base being about 25 ft. in diameter. This stone base was to enclose a small engine-room, so that the tower had to be supported directly over the engine-room. A steel angle-iron skewback was put in and a Guastavino arch formed. Then, to make a leveling for the tower, a contract was made with a certain party to fill the haunches, to a minimum thickness of 1 ft. over the crown, with Portland cement and broken-stone concrete. The men were careful to do what they called a good job. The concrete was mixed very dry—not quite as moist as brown sugar. It was thoroughly well tamped, and then exposed to the sun and wind, and dried out very quickly. The tower was put on before the speaker had an opportunity to inspect it. That concrete was just about as good as so much dried mud, and all of it had to be scraped out with shovels, with the occasional assistance of a pick and crowbar.

Mr. Lowinson. OSCAR LOWINSON, Assoc. M. Am. Soc. C. E.—In reference to the protection of metallic surfaces, especially those exposed to moisture, the subject that has troubled most engineers has been the question of what is known as the progressive oxidation of those surfaces; for the life of a structure is really dependent upon whether oxidation which started at any period in the life of that metal will continue.

Now, in connection with structural steel, it has been the speaker's custom to try to get all the rust off the metal before painting it. He has made examinations of metal painted with various kinds of paints, and found that oxidation frequently continued and caused increase in rust, very slightly perceptible for a while, but after several years becoming scaly and throwing off the paint. The proper protection of that metal by paint, he thinks, is necessary, especially when it is to be embedded in masonry, or in any case where that metal will be exposed to moisture, because iron or steel will only rust when oxygen, together with moisture and carbonic acid, is present.

It would be advisable at all times to make sure to have a protective coating of paint of some kind in addition to the pure cement. It is undoubtedly true that Portland cement is a good protective coating for steel, but it is also true that it is impossible to protect steel with a wash of Portland cement, for the reason that it will not adhere to the steel.

One question that has been touched slightly by Mr. Hill is occupying the attention of many architects at present, and, that is the protection of walls in order to prevent the attacks of the elements, principally the penetration of moisture. In fire-proof buildings, an effort is made to do away with furring, because it is found that in most cases

a furring course is not sufficient to prevent moisture from coming through the wall and destroying the plaster. Mr. Lowinson.

There are on the market at the present time a score of what are known as damp-resisting compounds, and which are supposed to serve as moisture repellants. Most of these are of no value whatever for this purpose.

These damp-resisting compounds may be divided into two classes: Those which are put on the inner surface of an exposed wall, the plaster being applied directly on the paint; and those which are applied on the exterior surface of a wall, over which is put a coat of good paint, for a finishing surface. Of the first variety, the only correct kind is a hydrocarbon compound, which should be free from tar, pitch and oil, and should also be proof against alkali. It should be a sticky or non-drying compound, to which cement mortar or plaster will adhere permanently, and which water or moisture cannot penetrate.

The second variety, for exterior use, is a chemical compound, of the nature of a quick-setting, very finely divided, hydraulic cement, applied as a paint, which, when partially set, cannot wash off in a rain storm, and which will take linseed-oil paint without peeling. An ordinary cement wash will absorb moisture, and disintegrate; not only this, but it is also common experience that linseed-oil paint will not adhere to a cement surface. The reason is that, in the hydration of cement, $Ca_2 O$ is set free, and, with linseed oil, forms a lime soap, which will wash off.

The theory of the setting of cement, largely accepted, is that an excess of moisture does not ordinarily injure it, but the cement in its setting has the inherent ability of rejecting all the unnecessary water in order to permit it to set properly and attain its hardness.

A sufficiently thick layer of cement mortar on the outside of a brick wall forms an excellent water resistant if it has time to set before moisture or frost attack it. There are two or three materials on the market at present, which the speaker believes are made of Portland cement, with mixtures of either caustic lime or oil, for the purpose of preventing moisture from getting into walls.

In building work it is a very serious problem to protect plaster properly from attacks of moisture, and a great deal of time must be devoted to the study of the subject before enough is known about the resisting ability of these materials, to determine whether or not they are being used properly.

HENRY B. SEAMAN, M. Am. Soc. C. E.—In speaking of the desirability of painting iron before embedding it in concrete, we should not lose sight of the fact that the present tendency is toward the use of steel-concrete construction; and, in that case, the steel should not be painted. The theory of the strength of this form of construction depends upon the adhesion of the concrete to the steel, and a coat of Mr. Seaman.

Mr. Seaman. paint will prevent this adhesion. In this case the twisting or roughness of the rods is all that prevents them from slipping. The lack of adhesion of concrete to painted iron was illustrated recently where a portion of the side-wall of the New York Subway was moved bodily off its foundation, to make room for an extra track. The side-wall was composed of I-beams, with concrete arches between, and, when it was moved from the foundation support, portions of the concrete arches slid down the I-beams as though they had been lubricated.

The requirement that steel should be bright and clean before being painted may be carried to unreasonable extremes. If paint keeps the oxygen from the iron, it will prevent further corrosion, even though slightly rusted when the paint is applied. It is necessary, however, to clean the iron of all scale, whether of rust or other material, which might cause the paint to flake off. A first coat of paint would probably adhere better to iron with a dull surface, than if the iron were bright.

A number of years ago it was generally considered that the Phœnix column would rust inside; and as evidence of this condition the rusty drain holes in the under side of horizontal chords of truss bridges were cited. In 1891, an examination of one of the columns of the Kinzua Viaduct was made, in order to ascertain the condition of its inside surface. The viaduct had been in service about nine years. One of the highest bents was selected, and a piece of iron, about 2 ins. in diameter, was cut from the underside of an inclined column, at a distance of about 2 ft. from the base. As the cutting was completed, the hard oxide-of-iron paint inside the column was broken along the edge of the cut and showed a clean bright surface on the iron. This demonstration needed no further argument, and indicated that iron would last indefinitely if kept from air and moisture. This fact would seem to be equally reassuring as to the life of "iron-skeleton" buildings constructed in recent years.

It is interesting to note the difference of opinion among various engineers as to the quantity of water desirable in mixing concrete. Some specifications require "water in such quantity that the concrete will not flush after being rammed," which may aid quick-setting, but can be fulfilled by a mixture almost dry. On the other hand, there is the requirement that it shall be floated, as mentioned by Mr. Hill, though some engineers consider that this would "drown" the cement. A medium between these two extremes is, perhaps, preferable, or, as General Gillmore used to say: "So much water shall be used as will just flush the surface of the concrete after thorough ramming." It is important, of course, that the concrete should be first thoroughly rammed solid against the steel surfaces.

Mr. Just. GEORGE A. JUST, M. Am. Soc. C. E.—In so far as the question under discussion relates to the deterioration of structural steel when

embedded in masonry, Mr. Miller's careful presentation of the condi- Mr. Just.
tions revealed by the demolition of the so-called "Pabst" Building is very interesting.

He is in error on one point, however. The structural frame did receive two coats of black (carbon) paint, one at the shops and a second coat during erection. This last coat was probably not applied with any greater care than is usual, under the rapid rate of construction which has now become characteristic for this class of buildings in New York City and elsewhere.

The limited life of skeleton buildings, by the early disintegration of the frames, because of their inaccessibility in the finished structure, which has been predicted so universally by laymen, is based on no knowledge or experience. Failure in this type is rather to be looked for from faulty design of frame or footings. It is gratifying, therefore, that the opportunity thus presented to inspect a frame once embedded in masonry shows it to be remarkably well preserved, considered as a whole. On the other hand, our deductions should be made guardedly, because of what is after all a short lapse of time. Just four years elapsed between the erection and the demolition of the structure. It was erected and painted in January, 1899.

The use of particular kinds of paint, and the measure of protection which they afford, has been given undue prominence in the last few years. The question is not as important as the agent of the paint manufacturer would have us believe. He has occupied entirely too much of our time, and is to-day the *bête noire* of the structural engineer. For instance, the paint now used on the New York Elevated Railway structures, and which answers its purpose, is practically the same as that which has been used by the engineers of the road for the last ten years or more.*

It is true that the circular chimney stack, which was painted with another kind of paint, the red oxide of iron ordinarily used by local boiler shops, seemed badly rusted on the outside, in strong contrast to the well-preserved columns located close to the stack; but, as a matter of fact, this stack, on exposure, was found not to be corroded, but was well covered with pigment. It appears, however, that the heat in the stack had destroyed the oil. The pigment could be readily removed by the hand, and rapid corrosion set in soon after exposure. It would seem, therefore, that any conclusion as to the lack of protection afforded by the asbestos jacket is untenable. This emphasizes the important office of oil in paint, or rather, the less important part which the pigment takes.

The case under discussion also adds little or nothing to our knowledge as to how much protection was afforded by the paint used, beyond the contained oil, for it may be cited that the oil in the threads

* *Transactions*, Am. Soc. C. E., Vol. XXXIII, p. 535.

Mr. Just. of the tie-rods and bolts was practically intact, and, where not broken by the nut, had formed a perfect protection against rust.

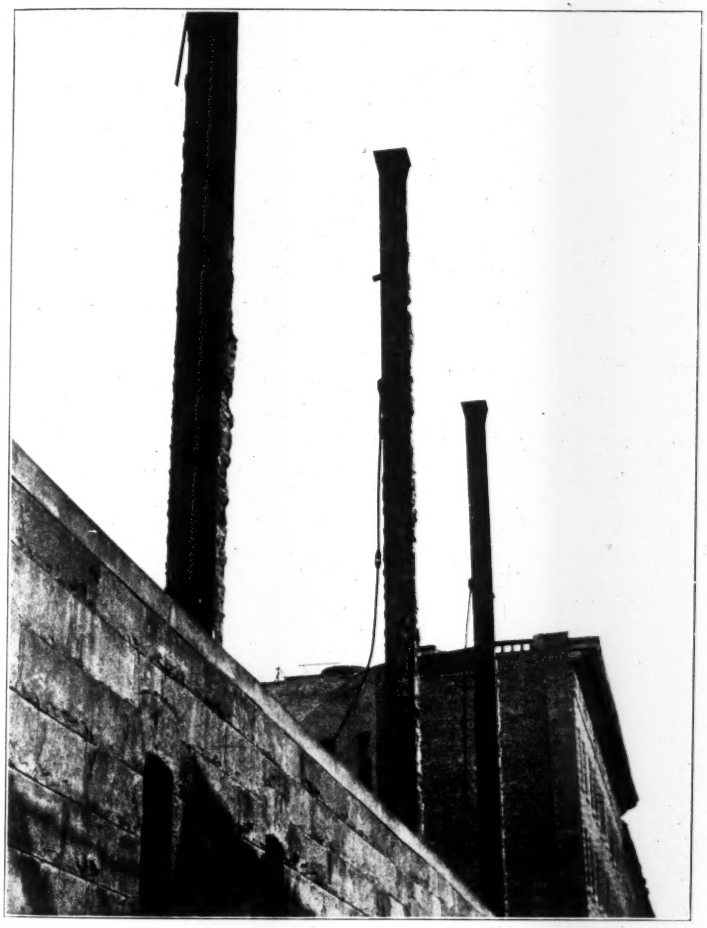
A further interesting development was the fact that the faces of the beam girders, stretching between the columns in the principal façade at some of the story levels, still retained an almost perfect coat of paint. Nor were they marked by any cement or mortar, but presented clean, black faces. It would appear, then, that at these points the front stone was not "backed" by brickwork, but was set away from the webs, and hence it may be concluded that, for limited periods, the steel, if only encased, is as fully protected as when embedded in brickwork.

While it may be granted that exposed iron and steel, when kept well painted, is protected against the deteriorating influence of rust, yet it is equally true that a sufficient number of instances has not been collated at this time to permit us to say the same of the painted steel frames embedded in the brick and stone walls of modern city structures, whose only excuse for existence is the use of walls of minimum thickness which they permit.

Instances, throwing additional light on this phase of the question, therefore, should be welcome. A better illustration than the "Pabst" Building, if measured by time, is found in the case of the Seventy-first Regiment Armory in New York City. Built for more than twelve years, and destroyed by fire one year ago, eight riveted (Z-bar) columns, Plate XXXII, which supported the main roof, now extend exposed from the northerly and southerly walls in which they were embedded. These walls, now removed for the upper half of the length of the columns, permit inspection. The columns, inaccessible for more than ten years, were probably subjected to considerable heat during the fire, and have now been exposed to the weather for more than a year. Notwithstanding all this, they show no appreciable deterioration by rust, which, while general over the surface, is only superficial. Paint, apparently the red oxide of iron used almost exclusively at that period, shows, in patches, where the brick filling has fallen away. It remains especially good between the flanges at the top for short distances below the cap, where the brick filling seems to have been omitted. For the rest of their length these columns were well enclosed on all sides by the brick laid in close contact with the metal. Much of this brick filling is still in place on the exposed part of the columns, and, where it no longer exists, the original courses of the brickwork are still marked against the columns by stripes of mortar.

An interesting case of column corrosion was recently noted in the uprights supporting the roof garden of the "New York Theatre," at Forty-fifth Street and Broadway, in New York City (Plate XXXIII).

The load of the all-glass roof is brought to the top of these uprights



COLUMNS OF SEVENTY-FIRST REGIMENT ARMORY.

by four intersecting trusses having curved lower chords. For decora- Mr. Just.
tive purposes, a part of each column, commencing some distance below the intersection of the curved chords with the column, and extending down to the floor line, was enclosed by two thicknesses of scenery canvas, which had been painted on both sides, and which was stretched over galvanized-wire cloth, which in turn was carried on furring strips consisting of small pieces of unpainted wood. This arrangement kept the envelope entirely clear of the column. Proposed alterations caused the removal of these jackets, when it was found that every column was entirely incrusted with rust scale, from the base plate of the column, under the floor, up to the point to which the jacket had extended. The unpainted wood furring and the galvanized wire were in excellent condition. Beyond this point, the columns, as also the intersecting overhead trusses, had received a second coat of paint. This coat was of lead with a light green pigment, which would indicate clearly even traces of rust. All this upper work, however, was rustless, and the paint in good condition. The lower and much rusted part of the column, it was plain, had never received any other paint than the "mill" coat, and, judging from what little remained, was of the usual red-oxide variety.

It was evident that the canvas jacket, for its entire length, prevented the rapid evaporation of the water of condensation from the roof, the flow of which the curved chords readily directed to and down each column. These columns have been in place about seven years.

In contradistinction to this case, it is interesting to note the condition of the interior surface of structural members, built up of shapes, in a manner to form closed sections. Twenty years ago, when the type of bridge popularly known as the "Phœnix" was first meeting serious criticism, because of its cast chord and post connections, and inaccessibility to the interior of these members for painting, a wreck of the Bell's Gap Bridge on the Delaware, Lackawanna and Western Railroad permitted a careful inspection. It was then found that the original coat of paint on the interior of the posts and chords was generally in a very good condition, notwithstanding their exposure since the wreck. This bridge when wrecked had been in place about eleven years.

Disks cut from similar columns, supporting a blast furnace, showed the original coat of paint on the interior surface to be almost perfect. These columns had been in place about fourteen years.

As to the condition of iron when buried in certain kinds of earth for long periods, Mr. Colin C. Simpson, of the Consolidated Gas Company of New York, says:

"Of the two 'bar-shots' in my possession, the larger weighs about 20 lbs., and consists of a square wrought bar 10 ins. long, with cast-iron hemispherical heads. It was found in the Kingsbridge Road near

Mr. Just. Dyckman Street in 1893. The heads are almost in a condition as when cast, while the wrought connecting bar is only pitted superficially. The smaller 'bar-shot' is entirely hand-forged, and weighs 8 lbs. It was found in about the same locality in 1895. This shot is in a good condition throughout, and the hammer marks are still plainly to be discerned. Cannon balls of several sizes are so well preserved that some of them still retain the marks of the flask in which they were cast. The soil in which these shots were found is clean, dry and loamy."

He adds:

"These missiles were fired, at the time of the American Revolution, from the British frigate *Pearl*, anchored in the Hudson River, off or near Dyckman Street, during the attack on Fort Washington, in November, 1776. They have lost practically no weight since their use 120 years ago."

The effect of lime and cement mortars, or of concrete, on embedded iron or steel, while well recognized, has received considerable attention in this discussion. In this connection it may be stated that the framers of the "Building Code," which at present regulates the con-

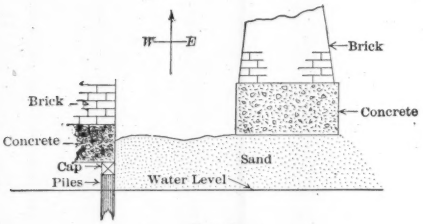


FIG. 2.

struction of buildings in New York City, recognized the protection which such materials afford to iron and steel, when embedded in them.

Section 25 of this code reads:

"Where metal is incorporated in or forms a part of a foundation it shall be thoroughly protected from rust by paint, asphaltum, concrete, or by such materials and in such manner as may be approved by the Commissioner of Buildings."

What appears to be a more serious question than the corrosion of these metals, however, confronts those engineers who have been engaged in the construction of our tremendously large and expensive buildings. This is the recession of the water level, which is certainly taking place, at least, in the lower part of Manhattan Island. This recession, probably due in part, to the large increase in the number of "sky-scrapers," vaults and subways, must have exposed to decay many pile foundations where this method of founding was used.

In proof of this assertion it may be stated that, for a building recently proposed in that section of New York City, a pile foundation

PLATE XXXIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. L, No. 949.
JUST ON PRESERVATION OF
MATERIALS OF CONSTRUCTION.

FIG. 1.—COLUMNS IN ROOF-GARDEN OF "NEW YORK THEATRE."

FIG. 2.—CORRODED COLUMN IN ROOF-GARDEN OF "NEW YORK THEATRE."

as originally designed had to be abandoned when, upon excavating the lot, it was found that the capping timbers and heads of the piles in the foundation of a large and prominent building adjoining on the west were no longer protected by water (see Fig. 2). The indications showed that a recession in the water level of at least 2 ft. had taken place, in the last ten or twelve years, or at the rate of 2 ins. per annum. Lest it be assumed that the piles under this building were originally not cut off at, or below, the water-line, it should be stated, on the authority of the engineer connected with the design and erection of the building immediately adjoining the proposed building on the east, that the concrete footings of that building were laid in water. This concrete base, of course, was also shown to be high and dry when the lot between the easterly and westerly buildings had been excavated to a sufficient depth. Mr. Just.

A. GIDEON, Assoc. M. Am. Soc. C. E.—From the data submitted by those who have discussed the method of preserving steel, it would seem as though no hard and fast rule could be made as to whether or not structural steel embedded in concrete should be painted first; as it depends largely on the conditions to which the metal is to be subjected, and the functions it is to perform. Each individual case should receive the careful attention of the engineer, and, not unlike many other engineering problems, is a question of judgment, guided by theory and experience. Mr. Gideon.

In cases where the adhesion of the concrete to the steel is of great importance, and where there is no danger of the concrete cracking and breaking off or peeling away from the metal, the previous painting of the steel would seem to be unnecessary, as the concrete would be an ample protection against rust, and greater adhesion of the concrete to the metal could be thus secured.

On the other hand, where the concrete is likely to crack and break off, thus admitting air and moisture, it would certainly be of the utmost importance to paint it as carefully as possible, and thus prevent it from rusting.

FRANKLIN RIFFLE, M. Am. Soc. C. E. (by letter).—The preservation of the steel frames of modern high buildings from corrosion is a matter of vital importance, not only to the engineer and architect, but to the general public as well. That the subject is not given the attention it deserves is only too apparent to the most casual observer. Mr. Riffle.

The writer knows of three skeleton buildings, now in process of construction, in which the columns and beams were neither oiled nor painted from the time they left the rolls at the mill until they were riveted in place.

At this stage they were given two coats of paint. Although the steel was badly rusted, no attempt was made to remove the rust before painting. The presumption is that the painting was designed to pre-

Mr. Riffle. vent further corrosion; but it is the writer's experience that paint applied to a coating of rust soon cracks and crumbles when exposed to the influences which promote oxidation. For this reason it is generally conceded, by engineers and architects who are familiar with steel construction, that paint, to be effective, should be applied to the clean metal, preferably at the shop, before corrosion begins, or, if later, not until every vestige of rust is first removed.

The fact that steel skeletons cannot be inspected after the buildings are completed and occupied should induce those who are directly responsible for their design and construction to take every reasonable precaution to preserve the metal from any possibility of corrosion. In the light of present knowledge, it is a grave question whether, under any circumstances, an architect is justified in assuming that the conditions in the interior of a building are such as to render corrosion impossible or even improbable. Examples are not wanting to prove that wrought-iron columns and beams encased in brick masonry sometimes corrode badly when not otherwise protected. In most steel-skeleton buildings the outside columns and beams are protected from the weather only by a mere shell of stone or brick. Walls of this character cannot prevent moisture from penetrating to the steel frame and causing oxidation. The engineer or architect who has faith in protection of this sort is paving the way for trouble. The failure of a single column or beam at some future period may result in serious consequences, involving the loss of both life and property. With such possibilities confronting him, is the engineer or architect justified in neglecting to adopt such precautionary measures, to render his work both safe and durable, as the present knowledge of the subject warrants?

Without undertaking to discuss the relative merits of the various steel preservatives now in use, the writer desires to call attention to the preservative qualities of Portland cement. Not many months ago, Mr. George W. Dickie, Manager of the Union Iron Works of San Francisco, stated to the writer that for many years, and with very satisfactory results, he had used Portland cement to protect iron and steel from corrosion. He stated that while recently repairing the iron hull of a ship he had occasion to remove a portion of the cement floor which had been laid some forty years before. The iron beneath the cement lining was found to be absolutely free from rust. For years it has been Mr. Dickie's practice to line the iron and steel water tanks of ships with Portland cement, applied as a wash, by means of a brush. He is quite pronounced in his belief that a protective coating of this character is a far more effective preventive of oxidation than most of the paints used for the purpose.

The fact that Mr. Dickie's experience as a ship builder has brought him in contact with the most active type of corrosion (that caused by

salt water) adds to the value of his observations, and is certainly a strong plea for the use of Portland cement as a steel preservative. Mr. Riffle.

EDWARD P. NORTH, M. Am. Soc. C. E.—Speaking solely of wood pavements: The first wooden pavement of record in this country was laid in 1835, on Broadway, New York City; another piece, about 100 ft. long, was laid in William Street, New York City, during the next year. There is no record available of the time that this lasted, and possibly (if plank roads are excepted) there was no wooden pavement laid in this country from that time until about 1852 or 1853, when a wooden pavement, known as the Nicholson pavement, was laid on a bridge in Boston. For this pavement, a prepared bed of coarse sand was made, on which were laid 1-in. boards, swabbed with hot coal-tar on both sides, and on these boards blocks of pine, 3 ins. wide and 6 ins. high, were placed, after being dipped in hot coal-tar. A strip of wood, 1 in. x 2 ins., was placed between each row of blocks, and the interstices thus formed were filled with clean gravel and flushed full of hot coal-tar. Mr. North.

Afterward the same pavement was laid in Chicago, in 1857 or 1858. From Chicago the use of this pavement spread over the West, and was brought to New York City in the time of Tweed.

Nearly all this pavement, with variants from it, rotted very fast. It was of untreated wood, and, further, was dipped in hot coal-tar, generally, but it was learned that with sufficient traffic such a wooden pavement would not rot before it wore out; that is to say, it would last six or eight years without showing any sign of dozing, if, during that time, it had sufficient traffic over it to wear it down from the original thickness to about $1\frac{3}{4}$ or 2 ins., when it commenced breaking up. But a pavement which was laid in places where the traffic was light very often commenced dozing in the course of two years, so that it was a shell at the end of five or six years.

These pavements, as laid in New York City, were so unsatisfactory, except one small piece in Fifth Avenue in the last of the seventies, that no wood pavement was laid until the end of 1895.

In England, the first pavement of record was laid in London in 1837. It was of beech. In London there was more or less continuous use of wood pavements, generally of hard wood, until about 1875, when patents were taken out by various persons, nearly all specifying that the wood should be treated with dead oil. In some the wood was saturated very thoroughly, and in others it was merely dipped in dead oil. A prejudice has grown up in England against treating pine or Baltic fir, which may be due to insufficient treatment, that of not saturating the wood fully.

Along in the last of the eighties, two specimens of wood grown on the southwest coast of Australia were brought to London for paving; one, the Karri wood, or *Eucalyptus diversicolor*, and the

Mr. North. other the Jarrah wood, or *Eucalyptus marginata*. They are hard, reddish woods, with a rather peculiar odor, and it is said that iron driven into them will not rust. Pavements of these woods were laid in London with very great success, the claim being made that the Karri wood will last longer than the Jarrah. The Karri wood was brought over to this country and laid in New York City in the winter of 1895, on Twentieth Street, on the block between Fifth Avenue and Broadway, the pavement being accepted in January, 1896. It was laid on a concrete foundation. The bottoms of the blocks, which were 5 or 6 ins. high, were dipped about 2 ins. in a preparation of pitch, the composition of which was kept secret, the pitch being so hot and fluid that the coating was only about $\frac{1}{16}$ in. thick. The blocks were driven together as tightly as they could be, conveniently, and the top was covered with a very thin grout of fine sand and Portland cement. The west end of that pavement, toward Fifth Avenue, has been entirely wrecked by the construction of two large buildings with deep foundations. The eastern end, toward Broadway, has been left intact, and a large area of it has not been disturbed. That has now lasted a few days more than seven years, as far as can be learned, entirely without repair, and it is in very good condition to-day, with the probability that at the end of four more years it will be in better condition than any granite pavement that has been laid in New York City. This is not a case of preserving wood, but of wood which preserves itself.

In regard to waterproofing brickwork, the attention of the members is called to a paper by the late William L. Dearborn, M. Am. Soc. C. E., read before this Society on May 4th, 1870, entitled "Experiments for Making Brick Masonry Impervious to Water, Tried on the Walls of the Back Bays of the Gate-Houses of the New Croton Reservoir in New York, and on the Brick Arch of High Bridge in 1863."*

Mr. Howe. HORACE J. HOWE, M. Am. Soc. C. E. (by letter).—Reference might profitably be made, it seems to the writer, to the remains of the habitations of the Ancient Lake Dwellers of Switzerland, as furnishing the best authentic instances of the preservation of wood and other substances under the most favorable conditions, from pre-historic times (in fact, from the New Stone and Copper Ages) up to the present time.

The building up of the habits and customs of that period, by means of somewhat advanced Sherlock Holmes methods, is very interesting, but hardly calls for more than a mention here.

In the winter of 1853–54, the waters of Lake Zurich fell to a remarkably low level, thereby revealing certain piles in the bottom, at no great distance off shore. These piles proved to be from 15 to 30 ft. in length and from 3 to 9 ins. in diameter. They were in rows, sometimes parallel to the shore, sometimes at right angles to it, and

Transactions, Am. Soc. C. E., Vol. I, p. 203.

were either firmly embedded in the mud or supported by heaps of stones at the base. Sometimes they were driven through boards which rested on the bottom. Mr. Howe.

The piles were braced together by means of transverse beams with wooden-pin connections, and planked over so as to form a platform on which the huts were built.

There was also a draw-bridge connection with the shore.

Few piles now project more than 2 ft. from the bottom. They are saturated so thoroughly with water that they are quite soft. Some of them appear like needles, which elsewhere have disappeared and left only a black disc. This is true, however, principally of the oldest, those of the Neolithic Age.

The point which entered into the mud still bears the marks of the fire and of the stone hatchets, or later on, of the metal hatchets. The manner of driving to so great a depth into the ground is difficult to imagine.

As to the various objects which give the key to the doings of this people, Sir John Lubbock says :*

"Lying among the piles are fragments of bone, horn, pottery and sometimes objects of bronze. Most of them are imbedded in the mud or hidden under the stones, but others lie on the bottom, yet uninjured; so that when, for the first time, I saw them through the transparent water, a momentary feeling of doubt as to their age rose in my mind. * * * The upper parts of the objects also, which are bathed by the water, are generally covered by a layer of carbonate of lime, while the lower part, which has sunk into the mud, is quite unaltered."

In many other Swiss lakes, habitations are indicated in like manner, and it is understood that the Swiss archæologists have made the most of a golden opportunity. The Antiquarian Society of Zurich—Keller and others—was one of the first to do so; and it is quite possible that an official correspondence with that society would be productive of results as to the present status of the entire subject.

THEODORE BELZNER, Jun. Am. Soc. C. E. (by letter).—Regarding the steel beams taken out of the sidewalk vault, mentioned by Mr. Parsons, it would be interesting to know whether these beams had received a shop coat of oil. Mr. Belzner.

Steel, embedded in concrete, such as grillage beams, etc., should be cleaned thoroughly. The writer does not think it necessary to have them painted; but, of course, this does not apply to steel which is partially embedded in concrete, such as the side columns, roof beams and girders having exposed surfaces, now being used in the construction of the New York Rapid Transit Subway. Steel which is partially embedded in concrete should be cleaned thoroughly, either by the sand-blast process or by brush and scraper, and then given a good priming

* "Pre-Historic Times."

Mr. Belzner. coat of red lead, to be followed by a protective coat of some standard carbon paint.

Mr. Crehore. WILLIAM W. CREHORE, M. Am. Soc. C. E. (by letter).—In the previous discussion of this subject one point concerning the protection of metals by paint seems to have been entirely lost sight of. When the first coat of paint is applied to the bare metal, the action is somewhat analogous to that which accompanies the application of the priming coat to a piece of soft pine; the oil soaks into the "pores" of the metal and carries the pigment with it. In cast iron the action is discernible to the naked eye, but it takes place also in steel, although to a less extent, on account of the greater density and, consequently, the less porosity of the latter.

Obviously, the oil in a paint is the conveyer, or the medium by which the pigment is brought in contact with the metal. The oil is, also, to a certain extent, a protector of the metal when it is itself protected by the pigment. Pure oil, by itself, unmixed with a pigment, will protect the metal as long as it lasts, but it very soon evaporates and is gone. In the mixture the oil which is outside, next the air, soon evaporates and leaves the pigment, while the oil which is inside, next the metal, remains there permanently because of the protection afforded by the outside pigment. In order to protect the coating next the metal more thoroughly, therefore, a second coat of paint should be applied as soon as possible after the first one is dry.

In view of this combined action of the oil and the pigment it follows that the further the pigment can be injected or carried into the pores of the metal, the better is the bond between the paint and the metal; and if the pigment itself is a good protector its efficiency is certainly increased rather than diminished by being well bonded. Owing to the great density of steel or iron, this action is very slight, in comparision with the absorptive power of wood, and its amount depends upon the fineness of the pigment, as well as upon the density of the metal. This is one reason why paints differ in efficiency as protectors of metal. The more finely ground pigment makes the better metal paint, other things being equal, and such a pigment is conveyed better by a thin oil than by any other. Then, too, the quantity of oil in the mixture is an important point, as well as the degree of completeness with which the oil and the pigment have been mixed together. The requirements, therefore, for a good metal paint are somewhat analogous to those for a good concrete. As, for the latter, there should be just enough cement to fill the interstices between and to cover completely each particle of sand, and just enough of the mixture to fill the interstices in the stone; so, for the former, the pigment should be ground fine enough to enter the pores of the metal, the oil should be of correct quantity, so that it is thoroughly filled or loaded with the pigment, and thin enough so that it will carry the pigment into

the pores of the metal. It seems, then, that to produce the ideal metal paint requires: (1) that the pigment should be a good protector, (2) that the pigment should be very finely ground, (3) that the oil should be pure and very thin, (4) that there should be just enough and not too much oil in the mixture, (5) that the two should be completely mixed together. Mr. Crehore.

Furthermore, to obtain the best results, such a paint must be applied next the bare metal itself, without any intermediate coating of oil or scales of rust, either of which obstructions will prevent the pigment from reaching the pores of the metal. The writer contends that the metal should be absolutely bright and clean before being painted. The fact, referred to by Mr. Seaman, that the first coat of paint will adhere better to metal with a dull surface than to metal with a bright surface is because the dull surface possesses the greater porosity of the two and consequently affords a better opportunity for bonding the paint. Experience, however, shows that to check rust which has once begun is impossible, but that it keeps on increasing even though covered with a good paint. In view of this fact it is best to have the metal cleaned by the sand-blast, before being painted, in order to insure the best results, with any paint.

The action of the cement in a concrete covering for metal work is practically the same as that of a good paint. The cement will adhere better to the metal if there be nothing between it and the bare surface of the metal; and the concrete forms fully as good protection, under ordinary conditions, as would a good paint. If, however, the metal is located where there is occasional moisture, ordinary concrete is not a sufficient protection, and in such a case the metal should be painted before being set. On the other hand, if the concrete and the steel are expected to act together to resist stress in combination, a coat of paint prevents bonding between the metal and the concrete, and then it should not be used.

That we have not sufficient data to establish indisputably the superiority of those paints which approach more nearly than others to the conditions above mentioned, is chiefly because this subject has never been handled scientifically. Most of our observations are general, or are made under different conditions, and nearly all the available data have been compiled by men who were biased or prejudiced by a personal interest in one or another party to the competition. Comparisons to determine the relative efficiencies of different paints should be made by an absolutely disinterested commission, and under sufficiently varied conditions to establish superiority in one or another of the points now in dispute; such points, for instance, as whether the pigment or the oil is the more important element in the durability and efficiency of paint; what substances make good pigments and what substances are absolutely without merit as pigments; what the

Mr. Crehore. comparative effect would be of deleterious chemical fumes on the pigments of different paints; whether a given paint is less efficient when put on with a spray than when rubbed in with a brush, etc., etc. The report of such a commission need not favor any one paint exclusively, but it should define thoroughly the principles on which the composition of a good paint is based, and it could divide all who entered the competition into classes or groups graded according to relative merit in certain important features of the examination.

The writer believes that several of the manufacturers of paint would not only enter their products for comparative examination and exhaustive tests, but also would be glad to share the necessary expense of such work, provided they were assured of the absolute fairness and impartiality of the tribunal and its ability to handle the subject in a spirit of practical and scientific research. A Special Committee appointed by this Society ought to carry the weight necessary to make its results of great value, and to induce those manufacturers who have any confidence in their products to enter the race voluntarily. Most engineers are in great need of some authoritative information on this subject, aside from the variety of conflicting data and theories gratuitously furnished by paint manufacturers, and cannot afford either the time or expense to investigate it individually.

Mr. Kenly. W. W. KENLY, M. Am. Soc. C. E.—Some six years ago, in compliance with a request from a former Superintendent of Buildings of New York City, the speaker prepared a paper relative to the corrosion of metal in old bridges, and the chemical action which takes place between plastering materials and iron or steel when in contact.

The evidence given in that paper, parts of which are quoted below, was taken from papers and discussions before this Society, and should be satisfactory and conclusive, as it represents the experience of some of the most distinguished of our members. In addition, the speaker gives the results of some tests, conducted by himself, as to the corrosive effect of certain wall-plastering materials upon enclosed metals.

"The writer has carefully examined the *Transactions* of the American Society of Civil Engineers in reference to this subject, and finds from said *Transactions* that it is positively and absolutely established that iron and steel when embedded in cement mortar is not corroded if the cement mortar remains intact, that is, not cracked or broken to such an extent that the fissures become filled with water or subject to the action of the atmosphere.

"The evidence is also positive and absolute that iron and steel are not corroded by lime mortar.

* * * * * * * *

"I quote the following records from the *Transactions* of the American Society of Civil Engineers.

"*First.*—'The caustic alkalies and alkaline earths prevent the oxida-

tion of iron by neutralizing the acids. Iron, therefore, does not corrode in alkaline solutions or when embedded in lime.'" * Mr. Kenly.

"*Second.*—'I don't know that it has any very direct bearing upon this particular question, but it only occurred to me to mention that we have found cement to be a valuable protection for a ship against oxidation from bilge water. I have seen it where these plates had been four or five years under the bilge water, when they were just as bright under the cement as when the ship was built. This has been the experience in the American and British navies, that cement applied to the surface of plate in the bilge water under the engine-room and fire-room does protect them against oxidation.'" †

"From the same paper I quote:

"*Third.*—'All I can say is that we uncovered about four lengths of the anchor chains in the Niagara Bridge, and the pins and bars there were entirely free from rust. In one place the bars and chains had been painted, and in picking off the cement that had covered them quite a chunk would come off, and underneath they looked as bright as new. The bright end of a pin that had been filed 25 years before looked just as if it had been filed that day. * * *

'The cement that Mr. Roebling used was Thorold cement. On the tops of the towers, the saddles and the cables lying in them were covered to a considerable depth with cement mortar and when it was removed the wires were perfectly clean and bright. They are so still.'‡

"And from the same paper:

"*Fourth.*—'That the large anchor bars of the East River Bridge when placed in the masonry had all spaces filled with rich, pure cement grout made of Rosendale cement.'§

"Also from the same paper:

"*Fifth.*—'In 1876, when the bridge over the Kentucky River was built for the crossing of the Cincinnati Southern Railway, several links of the anchorage of the Suspension Bridge which was partly built by Roebling at the same place in 1855 were dug out and were found in a perfect state of preservation, not a spot of rust being apparent on the bars; but the mortar in which they were imbedded was very compact and dry and of excellent quality.'‖

"I quote from the discussions on a recent paper entitled, "On Painting the Louisville and Jeffersonville Bridge."

"*Sixth.*—'The problem of the covering of iron with concrete or cement has probably been worked out more successfully in France than any other country. About a year ago the speaker made quite a study of concrete construction in buildings under several of the French systems, the Monier, the Melan, and others, and in every case the iron was covered directly with the cement, without paint or varnish or anything intervening.'¶

"From the discussion on a paper entitled, 'The Protection from Corrosion of Iron Work used as Covering for Railroad Tunnels.'

"*Seventh.*—'The cement mortar, I suppose, really does preserve the iron from the effects of rusting. Not long ago I heard Mr. Robert Moore describe the method of treating bolts for bridges, by which, instead of using lead and sulphur, Portland cement was used, and it

* Theodore Cooper, M. Am. Soc. C. E., Vol. XI, p. 425.
† H. S. Haines, M. Am. Soc. C. E., Vol. XXVIII, p. 366.
‡ L. L. Buck, M. Am. Soc. C. E., Vol. XXVIII, p. 367.
§ F. Collingwood, M. Am. Soc. C. E., Vol. XXVIII, p. 368.
‖ G. Bouscaren, M. Am. Soc. C. E., Vol. XXVIII, p. 370.
¶ R. W. Lesley, Assoc. Am. Soc. C. E., Vol. XXXIX. p. 33.

Mr. Kenly. was found that the bolts were much better preserved in every way against rust and against pulling.'*

"'As to the adhesion of cement to iron, it is well known that iron pipes coated with cement are laid down by the mile. These have been taken up in many places, but not because of lack of adhesion of the cement. I have taken up pipes that had been laid many years, knocked off the cement, and found the iron as bright as new. It occurs to me, therefore, that in the case treated of in this paper it would be well worth while to consider the propriety of applying the cement directly to the iron. The cement certainly preserves the iron from rust.'†

"The above record established the fact that cement mortar will protect iron and steel if the cement mortar is kept intact around the material.

"Now, as to the lime mortar. As you are no doubt aware, all natural cements are made of limestone. Lime, such as used for building purposes and cement, contains exactly the same ingredients as cement, the only difference being that they vary in proportions of said ingredients, thus: The lime used for building purposes, plastering, etc., is composed of 90% of carbonate of lime and the remaining 10% of what are called impurities, such as silica (sand), alumina (clay), manganese, etc., and a limestone makes a slightly hydraulic or eminently hydraulic cement, according to the variations of the proportions of the aforesaid impurities, thus: The eminently hydraulic cements contain about 65% of carbonate of lime and 35% of the aforesaid impurities, such as silica, aluminum, etc. Therefore, I have established by quotations from the above *Transactions* that the ingredients in cement mortar do not cause corrosion; therefore the same ingredients in lime mortar will not cause corrosion, as exactly the same materials are used in both cement and lime mortar, as both the cement and lime are mixed with sand to make mortar.

"In support of this argument I submit the following practical experience. During the construction of the extension of the Sixth Avenue Elevated Railroad, Phœnix iron columns were used. These, as you are aware, are closed columns, and are inaccessible to painting after being erected, and this has always been a serious objection to the use of the Phœnix column. In order to overcome this inability to paint the interior of these columns and to protect the interior of the columns from corrosion, the columns, especially around the "S" curve from One Hundred and Tenth to One Hundred and Fourteenth Streets, were filled with ordinary lime mortar to prevent them from corroding on the interior surfaces. Mr. Edward Wegmann, now Division Engineer of the Croton Aqueduct, with headquarters at Katonah, New York, was the Engineer in charge of this work, I have been informed.

"*Second.*—Mr. Prince, of the firm of Prince and Kinkel, Ironworkers and Contractors, of this city, has informed me that he has taken down ironwork which had been erected over 25 years and which was covered directly with ordinary lime mortar and the ironwork was as bright as when first erected, and entirely free from corrosion.

"*Third.*—I have previously quoted from the paper, 'Discussion on the Care and Maintenance of Iron Bridges,' the statement of Mr. Theodore Cooper as follows:

"'The caustic alkalies and alkaline earths prevent the oxidation

* Desmond FitzGerald, M. Am. Soc. C. E., Vol. XXVII, p. 330.
† J. P. Frizell, M. Am. Soc. C. E., Vol. XXVII, p. 330.

of iron by neutralizing the acids. Iron, therefore, does not corrode in alkaline solutions or when imbedded in lime.' Mr. Kenly.

"*Fourth.*—I quote from a * * * report made by William H. Burr, M. Am. Soc. C. E., Consulting Engineer, * * * formerly Engineer of Construction and later the General Manager of the Phœnix Bridge Company, of Phœnixville, Pa. * * * Mr. Burr made this report as the result of competitive tests done at the Bowling Green Building in August, 1896, on the Roebling wire partition. Lime plastering mortar, gauged with Atlas Portland cement, was used. Mr. Burr says in his report, 'The net-work was thoroughly imbedded in the scratch coat, and I could discover no sensible corrosion of the wires.' I will refer to this report later on, in another connection.

"I quote again from a report made by Mr. A. J. Robinson, of the well-known firm of Robinson and Wallace, Builders, of this city, being a report of the aforesaid competitive test done on the Roebling wire partition. Mr. Robinson reports as follows: 'I found no rust on the wire from lime-gauged machine mortar.' I will refer to this report later on.

"I also quote from the report made by Mr. Isaac E. Ditmars, Architect, of the well known firm of Shickel and Ditmars, Architects, on the aforesaid competitive test at the Bowling Green Building. Mr. Ditmars reports as follows: 'That I found the lime plastering mortar gauged with Portland cement did not appear to rust the wire.'

"Returning again to the *Transactions* of the American Society of Civil Engineers, I find in the paper on the Restoration of the Cable Ends of the Covington and Cincinnati Suspension Bridge, when the cables were removed, Mr. Bouscaren, Engineer-in-Charge, reports that the mortar in immediate contact with the wires was impregnated with iron rust, and formed a very hard crust around the strands.

"'The outside wires of the strands were, as a rule, bonded together in a matrix of rust, giving to the strands the appearance of solid bars, yet in a few spots the wires were bright and well preserved.'

Mr. Bouscaren gives this description of the character of the masonry:

"'The character of the masonry was poor, the vertical joints and beds between the dimension stones of the casing were very irregular in thickness and imperfectly filled with mortar; numerous cavities were found in the rubble filling, which in the case of the northwest wall were of sufficient size to admit freely the full length of a man's arm. The mortar was very irregular in quality and showed great variation in the proportions of sand and lime used with the cement; as a rule it was defective in hardness and saturated with moisture, especially in the immediate neighborhood of the cable strands which had been bedded and grouted in the rubble. Quite a number of wooden chips and wedges were found imbedded in the mortar and reduced to the consistency of a soft pulp by the united action of air and water; in the case of the northwest abutment, a piece of yellow pine scantling over 4 ft. long was found in the mortar between the strands.'

"In the discussion of this statement of Mr. Bouscaren, Mr. Theodore Cooper said as follows:

"'As far as this case goes, the faith of Mr. Roebling and other engineers in the preservative effects of cement mortar need not be shaken, for, from the author's description of the masonry, and the wooden blocks and chips imbedded therein, the cables were not imbedded in cement mortar.'

Mr. Kenly. "And, also, that 'the conditions necessary to preserve iron from corrosion, as we understand them, are total exclusion of acid substance, or of any material which may, by its own changes, produce any acid action.'

"'That percolating through cement has any acids contained therein neutralized is the natural explanation of the preservative character of cement mortar. If, however, the cement covering be imperfect, so that any water can pass without this neutralizing of the acids, oxidation must be expected.'

"In the same discussion Mr. Whinery said:

"'Mr. President, I have imagined that the effect of mortar upon iron depended somewhat upon the constituents of the cement. Cement that contains a very small amount of, or, no, sulphur, would, I imagine, protect the iron pretty thoroughly. But I think a small percentage of sulphur, which all our natural cements contain, might account for the corrosive action of the cement to a great extent.'

"The simplest proof that lime mortar and lime mortar gauged with cement does not corrode iron or steel is the fact that the operative plasterers leave their steel tools in lime mortar and in the lime mortar gauged with cement over night and for many consecutive hours in the aforesaid mortar, and on taking out said tools they find they are not rusted.

"Having now discussed the corrosive effects of lime mortar and cement mortar upon iron and steel, we come to the discussion of the patent plasters or so-called hard plasters. In a recent circular issued by one of the patent plaster companies, in July, 1897, we find the following: 'Our method of manufacture renders the patent plaster the only material that does not corrode iron, metal lath or nail heads.' We will now see if this statement is correct. In August, 1896, a competitive test was made in the Bowling Green Building, Nos. 5–11 Broadway, between lime mortar gauged with Atlas Portland cement, and the aforesaid patent plaster, done on the Roebling wire partition. At the writer's solicitation, Mr. William H. Burr * * * made a report as to the results, from which the following is quoted:

"'I found that the patent plaster had induced active and serious corrosion of the wire holding it in all the numerous instances (I believe without exception) where I had opportunity to observe this effect. In all these examinations I found the patent plaster materially inferior in respect to qualities of hardness and tenacity, and lacking monolithic character as well as possessing some quality which induces active corrosion of the wire partition. This latter effect might produce a serious result, in some instances at least, in a comparatively short time.

"'The results of this examination exhibit the superior excellences of Portland cement as an agent for giving strength and hardness to wall plaster, and it possesses the additional valuable quality of preserving the wire partition against corrosion, whereas some element in the patent plaster actively induces it.

"Mr. Burr stated that he could discover no sensible corrosion of the wires from cement-gauged lime mortar.

"In the report of Mr. A. J. Robinson, on the aforesaid competitive test on the Roebling wire partition, he states: 'I found, where I could observe it, that the wire was badly corroded where the patent plaster had been used.

"The principal cementing material of the patent plasters, or so-called hard plasters, is 'gypsum' or 'Plaster of Paris,' known

in chemistry as 'sulphate of lime,' and according to a recent authority* its chemical analysis shows, acid, 46 parts; lime, 32 parts; water, 22 parts. Mr. Kenly.

"In the discussion on the Care and Maintenance of Bridges, Mr. Theodore Cooper, states as follows:

"'Ordinary commercial sulphur generally contains sulphuric and sulphurous acids, produced by the oxidation of the sulphur during its process of sublimation. These acids are the immediate corroding agents when the impure sulphur and iron are in contact.'

"'In general, the rusting or corrosion of iron only takes place in the presence of an acid and moisture.'

"'In dry air at common temperatures, or under pure water free from air and carbonic acid, iron does not oxidize. Neither does it oxidize in dry carbonic acid gas; nor to any great extent, if at all, in damp oxygen. But in the presence of moisture and many acids the corrosion takes place readily and continuously.'

"Thus, according to this authority, in the 'presence of moisture and many acids the corrosion takes place readily and continuously.' I will now show that the patent plasters contain both the moisture and the acids necessary to start the corrosion.

"One of the claims of the various patent plasters is that by the use of their material the plastering of a building can be done so much quicker from the fact that their mortar becomes hard, or 'sets,' in a few hours, and in many cases the white coat is applied the following day. Although the patent plasters 'set' and become hard, they are not dried out, because it requires just as much water to put the patent plasters in a plastic condition ready to be applied to the iron lath or wire as it does to make lime mortar in the same condition, and it is the universal custom to allow the lime mortar to dry out thoroughly or become 'bone dry.' Thus, at the time the lime mortar is coated with the white coat the lime mortar in contact with the metal lath or iron wire, the lime mortar is dry. On the contrary, the water in the patent plasters is not dried out and there is a moisture or water in the patent plaster in combination with the 'sulphate of lime' and other acids used in the preparation of the aforesaid patent plasters.

"It is a well-known fact among practical plasterers that walls and ceilings done with the patent plasters will, under certain conditions, sweat for many months after the plaster is applied, thus showing the presence of continued dampness or moisture.

"In the patent papers of one patent plaster company it is stated that both sulphuric and muriatic acids are used in the composition of this plaster. * * * The simplest proof that patent plasters corrode iron and steel is the fact that the operative plasterers find that when they leave their steel tools in the patent plasters over night they are found to be corroded the next morning.

"Mr. W. B. Corney, of the firm of W. B. Corney and Brother, Plasterers, of this city, has informed the writer that he had repaired a ceiling of a building situated on Sixth Avenue, at about Thirtieth Street, and found that the metal lath was entirely corroded and gone, and there was nothing but a shell of plaster composing the ceiling. He further stated that the plaster was a "patent plaster," but did not know which one.* * *"

A test was recently made at the new addition of the Metropolitan Life Insurance Company's Building on Twenty-third Street, New York

* Millar.—"Plain and Decorative Plastering."

Mr. Kenly. City, to determine the corrosive effect of plastering materials upon metals.

Pieces of cast iron were broken, and a plastering material consisting of lime mortar and Portland cement was applied to the clean, bright fracture of one piece; and a sample of patent plaster was applied to the clean, bright fracture of another piece.

About a month after, the two samples of plastering material were removed, and the piece of cast iron to which the cement-gauged lime mortar had been applied was as clean and bright as when first broken; but the second piece of cast iron, which had been covered with the patent plaster, was corroded.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 950.

ADDRESS AT THE ANNUAL CONVENTION AT ASHEVILLE, N. C., JUNE 9TH, 1903.

THE DEVELOPMENT OF THE COMMERCE OF THE GREAT LAKES.

By ALFRED NOBLE, President, Am. Soc. C. E.

In selecting a subject for this occasion, it has seemed to me that I would be more likely to interest you in a topic of specific engineering and commercial development than in one of those broader subjects, always of interest to professional men, which have been treated so ably by my predecessors.

The example I shall present is one with which I have happened to be in contact more or less for more than thirty years. This development is largely the result of engineering work, and thus its study is in our field. I shall therefore ask your indulgent attention to such facts and conclusions as I may present regarding the Development of the Commerce of the Great Lakes. In the main, I shall confine myself to the portion of the Great Lakes System lying above Niagara Falls, which forms a well-defined unit.

In the light of more recent history, it seems at first surprising that so much time elapsed after the occupation of tropical America before serious attention was given to that part of the continent where the greatest development has since been made. In Spanish America, a high degree of civilization, for the time, had been reached before the English had obtained a foothold in North America; and the French, as a civilized community, had little more than standing room along the

margin of the St. Lawrence more than a century after the great achievement of Columbus. Much information concerning the areas immediately bordering the Lakes was given by the missionaries, who left admirable records; and some information of the regions further inland was obtained by the *coureurs-de-bois*, who made few records; but the Mississippi Valley was practically unknown until nearly two centuries after Columbus, when La Salle undertook his heroic task. As a first step he became a shipbuilder.

The launching, in 1679, of La Salle's schooner, the *Griffin*, a vessel of about 45 tons, marked the inauguration of modern navigation on the Lakes above the Falls of Niagara. A little hamlet, at the mouth of Cayuga Creek, a short distance above the Falls on the American side, bearing the name of the intrepid explorer, marks the site of the first shipyard on the shores of these waters.

It was expected that the *Griffin* would serve to advance the exploration, not only by conveying La Salle and his party to Lake Michigan, but, by engaging in the fur trade, its profits would supply in large part the money needed to sustain his work. After landing on the shore of Green Bay, he loaded the vessel with furs and sent it on its way to the foot of Lake Erie. It was never again heard from. Whether it disappeared through the fury of storms, treachery of the savages or cupidity of its own crew, is one of the mysteries of these inland seas. This seems to have been the only attempt to place a modern craft on the Lakes for many years. I have been able to find no record of any other vessels on Lake Erie until after the capture of Fort Niagara by the British in 1759, when they began at once to build vessels above the Falls.* During the siege of Detroit by Pontiac, in 1763, two small vessels, the *Gladwyn* and the *Beaver*, lay at anchor in front of the post; thus it would appear that nearly another century had passed—or nearly three centuries after Columbus—before modern navigation was resumed on the Lakes between the Falls of St. Mary and the Falls of Niagara.

Such commerce as existed on the Great Lakes in those early days was mostly confined to the trade in furs, and converged at Montreal, the head of ship navigation on the St. Lawrence. This was carried on the Lakes mainly in canoes and craft 30 to 50 ft. long, propelled by paddles, called barges by the English and *bateaux* by the French.

*"The Commerce and Shipping of the Great Lakes." A special report by Mr. C. H. Keep, of Buffalo, N. Y.

From such meager records as are at hand it seems probable that, after the unfortunate *Griffin*, sail navigation had an earlier development on Lake Superior than on Lake Erie. It appears, indeed, that a Frenchman named La Ronde built a bark of 40 tons above the St. Mary's Falls or Rapids about 1731, the rigging and other materials being sent from Lower Canada in canoes.* It is stated by Captain Jonathan Carver, who traversed Lake Superior in 1766, that the French, "while in possession of Canada, kept a small schooner on this lake." The loss of this vessel is reported soon after the conquest of Canada by the British.† The discovery of copper led to the building of a sloop of 70 tons, above the St. Mary's Falls, which was launched in 1772. It was used in prosecuting mining enterprises until their collapse a year or two later, when it probably passed into the hands of the fur traders who from this time monopolized the commerce of Lake Superior for many years.†

The early history of Lake commerce could not be understood without a reference to the remarkable commercial organizations which were formed mainly for the trade in furs. The first and most important was the Hudson Bay Company, which was chartered by Charles II in 1670 under the name of "The Governor and Company of Adventurers of England trading into Hudson Bay." It had the exclusive right to trade in and govern all the territory draining into Hudson Bay. For more than a century it exercised these privileges without opposition, except as operations brought its agents in contact with the French, then in control of the basin of the Great Lakes. Soon after this territory passed under British control, in 1763, the superior advantages of the Lake Superior route to the region northwest of it became manifest. In 1783, the year when the Independence of the United States was acknowledged by treaty, the Northwest Company was organized at Montreal, and at once became a vigorous competitor of the older company, extending its operations across the continent. Its success stimulated the formation of other companies, among others the American Fur Company, a pseudonym for John Jacob Astor. The interests on the British side of the boundary were practically unified in 1821 by the amalgamation of the Hudson Bay and Northwest Companies under the name of the former. About 1870 the company gave

* Dr. James D. Butler, in a paper for the Michigan State Historical Society, on "Early Shipping on Lake Superior."

† Butler.

up its power to govern the vast territory over which it had so long held absolute sway, and became a purely commercial organization. Its business is said to be greater now than ever before.

The Northwest Company employed sailing vessels soon after it was organized, and before the end of the 18th century had at least one on Lake Superior and one on Lake Huron. At the beginning of the war of 1812 the company reported to the Canadian Government that they would place at its disposal on Lake Superior one vessel of 120 tons which could carry six or eight guns, and another of 60 tons. These and three others were captured by the Americans; and another, cleverly hidden in an obscure harbor at the east end of Isle Royale, escaped detection, and after the close of the war was run down the St. Mary's Rapids for service on Lake Erie.*

The year after the war closed, Congress passed an act prohibiting British fur traders from prosecuting their enterprises within the territory of the United States. This gave the American Fur Company its opportunity, and, before many years had elapsed, it had sailing vessels both above and below the St. Mary's Rapids. It is not certain that the British companies again placed sailing vessels on Lake Superior.

The British, however, were not entirely driven from the lake. They had a schooner in service in 1822 and 1823, in which Lieutenant Bayfield, of the Royal Navy, made a survey of the lake. Considering the time consumed and the means at hand it was wonderfully well done. The shore line and depth of water, islands and sunken rocks, were represented with surprising accuracy and detail, and Bayfield's charts remained standard for fifty years.

While the British had sailing vessels on Lake Erie in 1759, and probably continuously thereafter, no American vessel was built above the Falls of Niagara until 1797, when the schooner *Washington* was launched at Erie. It was sold the following year to a Canadian, and carried on wheels around the Falls to Lake Ontario.† There were no other American vessels on Lake Erie for some years, but, at the outbreak of the war with Great Britain, several small ones were found in service on both sides of the boundary, and formed parts of the hostile fleets. The larger vessels of Perry's fleet were built at Erie in 1813. It is said that they were built from standing timber in seventy days.

* Butler.
† Keep.

The famous battle of Lake Erie, fought on September 13th, 1813, gave the Americans supremacy on these waters, and it has been maintained ever since. It is worth noting that the aggregate tonnage of the two fleets in this celebrated battle was less than that of a modern lake freighter of moderate size.

After the war, the tide of emigration set strongly to the territory bordering on the Lakes. Sailing vessels multiplied, and in 1818 the first steamboat above Niagara Falls was launched at Black Rock, now a part of Buffalo, then the principal Lake Erie port, and on August 25th started on its first trip to Detroit. With great propriety, it was named *Walk-in-the-Water*, for it appears to have been capable of no more rapid pace. From nine to ten days were required for a round trip. The port of Black Rock was on the Niagara River, below the rapid current, at the outlet of the Lake. Unassisted, the *Walk-in-the-Water* could not stem the current and was regularly assisted, when starting on its westward trip, by what was called a "horned breeze," several yoke of oxen being attached to the boat and hauling it to the Lake.*

An event was now approaching which was to have immediate and far-reaching industrial results. This was the opening of the Erie Canal, giving convenient access to the Lake region and an outlet for its agricultural products.

It appears probable that a canal to connect Lake Erie directly with the Hudson River was first proposed by Gouverneur Morris in 1803, but the suggestion was considered "the effusion of an eccentric mind indulging in romantic and visionary schemes." Within four or five years its merits became more generally perceived, and in April, 1808, an act of the Legislature of New York authorized a survey of the route, and appropriated for it the magnificent sum of $600. Mr. James Geddes was appointed the first engineer, made the survey and submitted his report early in the following January. It did not include an estimate of cost, but this was supplied two years later by a State Commission as $5 000 000. A loan of the amount was authorized by the Legislature, but the act was subsequently repealed.

The Commission referred to was composed of some of the most eminent citizens of the State. After submitting its report, with the estimate above noted, its membership was increased, and a second report was made in 1812. From this time, for several years, nothing de-

* Keep.

cisive was done, but the sentiment in favor of the project was gathering strength, and in 1816 a Board of Canal Commissioners was appointed, who employed engineers, fixed the dimensions of the prism and locks and inaugurated the work, breaking ground at Rome, July 4th, 1817. The President of the Board was De Witt Clinton, the most powerful and persistent advocate of the project.*

A few months before the inauguration of the work at Rome, a joint committee of the Legislature reported that the cost of transportation from Buffalo to Montreal was $30 per ton, and the returning transportation from $60 to $75. The expense of transportation from Buffalo to New York was stated at $100 per ton, and the length of passage twenty days. In 1852 Mr. Israel P. Andrews, in a striking "Report on the Trade and Commerce of the British North American Colonies and upon the Trade of the Great Lakes and Rivers," commented on these rates in the following forcible words:

"Upon the very route through which the heaviest and cheapest products of the West are now sent to market, the cost of transportation equalled nearly *three* times the market value of wheat in New York; *six* times the value of corn; *twelve* times the value of oats; and far exceeded the value of most kinds of cured provisions."

These comparisons show how absolutely impossible the development of the Northwest would have been at that time without the cheaper transportation afforded by the canals.

Among the most effective reasons given for the building of the Erie Canal was the need of counterbalancing the advantages of the natural route down the St. Lawrence. In a memorial, presented to the Legislature in 1816, commenting on the route proposed by way of Lake Ontario, it was said, "the most serious objection against the Ontario route is, that it would inevitably enrich the territory of a foreign power at the expense of the United States."* Indeed, the battle between the Northwest and New York, the one contending for the cheapest outlet to the seaboard, the other for a waterway through its own territory and for the development of its own wealth, was fairly joined at that early day. With the Erie Canal, victory was secured for the Empire State, and the supremacy of the port of New York established for at least a century.

* The data relating to the early history of the Erie Canal have been extracted mainly from a "Documentary Sketch of the New York State Canals," by S. H. Sweet, Deputy State Engineer and Surveyor, 1862.

These consequences followed from a ditch that at the present time seems insignificant. The bottom width was 28 ft., at the water surface 40 ft. Its depth was 4 ft. The locks were 90 ft. long and 12 ft. wide. The magnitude of the canal is well set forth in a record of the time: "Three Irishmen finished three rods of canal, 4-ft. cutting, in 5½ days."* It was opened through to Lake Erie on October 26th, 1825, and navigated by boats of 35 to 45 tons. It had cost about $7 000 000.*

The building of the Erie Canal stimulated the spirit of enterprise in neighboring States, and in 1825 the State of Ohio began a canal system, connecting Lake Erie with the Ohio River, and, by branches, with various points within the State. The main lines were completed in 1832. The system attained a total length of nearly 900 miles, and in 1852 their total cost had amounted to more than $15 000 000; their width at bottom was 40 ft. and their depth 4 ft., the same as the Erie Canal. In 1826 the State of Pennsylvania inaugurated the great Pennsylvania line of improvement—part railroad, part canal—extending from Philadelphia to Pittsburg, with branches connecting with Lake Erie *via* Ohio canals and directly with Lake Erie at Erie.†

The Wabash and Erie Canal, by which the interior of Indiana was brought in water communication with Lake Erie at Toledo, gave an outlet to the corn crop on which Northern Indiana depended, and made Toledo for many years the chief shipping point of this staple. It was 60 ft. wide and 4 ft. deep, east of Fort Wayne, and 40 ft. x 3 ft. westward.† A water communication between Lake Michigan and the Mississippi was advocated from a very early day; the Illinois and Michigan Canal was commenced in 1836, and opened in 1848, with a channel 60 ft. wide and 6 ft. deep, and provided for boats of 150 tons. Its summit level was only 8 ft. above Lake Michigan.† A second line of communication between these waters was begun in 1848, to connect the Fox and Wisconsin Rivers, the former discharging through Green Bay into Lake Michigan, the latter into the Mississippi, with headwaters only two miles apart.

None of these canals connecting the great lakes with tributary districts is now an important factor in Lake commerce. Some have been sold, others have been retained in use, but with diminishing traffic and a constant expense to the communities owning them.

* Sweet.
† Andrews.

As the opening of the Erie Canal drew near, the improvement of Lake harbors became most urgent. The Port of Buffalo was soon to take first place as the terminus of the canal. A survey of the harbor was made by the State engineers in 1819, but it was perhaps due to the prominence given the neighboring harbor of Erie, in the war then just passed, by the building of Perry's fleet, that the latter was the first lake harbor to receive an appropriation from the General Government. By Act of Congress, approved March 3d, 1823, an appropriation of $150 was made for a survey of the harbor of Erie, which was carried out under the direction of the Corps of Engineers of the Army, and plans for the improvement were presented by a Board of Engineers on the 4th day of October following.

By Act of Congress approved May 26th, 1824, the sum of $20 000 was appropriated for the work, and operations were commenced the same year. This appears to be the earliest appropriation made by the General Government for harbor improvements. Much doubt existed as to the constitutional right of Congress thus to dispose of public money. Appropriations for other harbors soon followed, but the entire amount for the Lakes above the Falls, up to the end of 1829, was less than $250 000. In the next decade the total was $1 250 000; in the next, about $400 000; in the decade of the '50's, less than $500 000, and in the period from 1860 to 1865, inclusive, embracing the civil war, the total was but little more than $500 000. The period of larger appropriations began in 1866.

Another impetus was given to Lake commerce in 1829 by the opening of the Welland Canal, in Canada, between Lakes Erie and Ontario, by which the obstruction to navigation toward the sea, by the Falls of Niagara, was at last overcome. The first vessels through it ascended from Lake Ontario, one of the first two being of 85 tons burthen. The canal and locks permitted the passage of vessels drawing 7½ ft., with beam of 21½ ft. An extension giving more direct communication with Lake Erie was commenced immediately, and opened in 1833. The work had been executed by a corporation assisted by the Governments of Upper and Lower Canada. Immediately after the union of these Provinces, in 1841, the Government acquired all the stock and took up the task of completing the canal system to tide-water at Montreal. The Welland was enlarged, and, at the end of 1848, the St. Lawrence navigation had been improved to such an extent that vessels drawing

9 ft. of water could pass from Lake Erie to the sea. The locks were generally 150 ft. long and 26½ ft. wide.* Numerous sailing vessels and steamboats were built whose dimensions were fixed by these lock dimensions. When I first became acquainted with Lake commerce, in 1870, a large share of the vessel tonnage consisted of so-called "canal vessels" built to run between ports on Lake Ontario and the Upper Lakes. These were mostly sailing vessels, but there were also many steamboats, a single line having about thirty in constant service. Some of the sailing vessels are still in use.

It is beyond the scope of this address to make more than a reference to the magnificent system of waterways by which, as now developed, vessels drawing 14 ft. can pass from the Great Lakes to tide-water at Montreal. On this development the Government of Canada has expended $67 000 000,† a far greater amount in proportion to its resources than the Government of the United States has expended on all its waterways.

It was evident very soon after the opening of the Erie Canal that it must be enlarged, and only ten years afterward the enlargement was commenced. Its execution required twenty-seven years, and was completed in 1862, giving a prism 56 ft. wide on the bottom and 7 ft. deep, with locks 110 ft. long and 18 ft. wide, allowing the passage of boats carrying 240 tons of freight. The enlargement had cost $32 000 000.‡ In 1895 a further enlargement, giving 8 ft. over the miter-sills and 9 ft. in the prism, was inaugurated, but suspended because of the unexpectedly great cost.

The effect of the opening of the Erie Canal on Lake commerce was immediate; in fact, as the completion of the waterway drew near, its advantages were to some extent anticipated.

"In 1813 the whole tonnage of the Lake vessels at all the Lake Erie ports, including Detroit, was 2 067 tons. The vessels ranged from 10 to 99 tons, except two, which were 102 and 134 tons, respectively.

"In 1819 there were registered in the customs district of Buffalo Creek seven vessels, with a total tonnage of 473 tons, but of these seven vessels one was a steamer"§ (none other than the redoubtable *Walk-in-the-Water*).

* Data regarding the Welland Canal and the St. Lawrence Canal are obtained from "General Report of the Commissioner of Public Works," of Canada, for 1867.

† Report of Department of Railways and Canals, 1901.

‡ Sweet.

§ Keep.

The increase in shipping, from this time forward, was too rapid to be followed in detail here. The growth during the next few decades is summarized by Andrews as follows:

In 1825, the year of the opening of the Erie Canal, the tonnage above Niagara Falls consisted of three steamers of.....	772	tons,
And fifty-four sailing craft of.....	1 677	"
Making a total of.....	2 449	tons.
In 1830 this had increased to.....	16 300	tons.
" 1835 " " " ".....	30 602	"
" 1841 " " " ".....	55 181	"
" 1846 " " " ".....	90 000	"
" 1851 " " " ".....	153 426	"
" 1862 " " " ".....	383 309	"*

The dimensions of vessels had also increased rapidly. In 1839 the twenty-five largest steamers had an average burthen of 449 tons, the largest one being of 800 tons. In 1851 the average of the twenty-five largest was nearly 1 000 tons, and of the whole steam fleet, of one hundred and fifty-seven vessels, 437 tons. The most remarkable feature of the period from 1840 to 1860 was the development and decline of the passenger traffic. A number of boats engaged in this traffic were of 1 000 tons and upward. The *Western Metropolis*, owned and operated by the Michigan Southern and Northern Indiana Railroad Company, was 340 ft. long, and was run regularly at 19 miles per hour. Its route was between Buffalo and Toledo, the Lake Shore Railroad not having been completed. On the opening of that road, affording an outlet for the Michigan Southern and Northern Indiana, and the opening of the Great Western of Canada, giving the Michigan Central an outlet, the passenger traffic quickly declined, the engines were removed from several steamers, and the hulls converted into sailing vessels, and in some cases into dry docks. It was not until very recent years that these steamers were equalled on the Lakes, either in dimensions, speed or elegance of equipment.

Up to 1836 the direction of grain shipments through the Straits of Mackinaw was toward the west. In that year the first cargo of grain from Lake Michigan was received at Buffalo, and by 1840 this traffic

* But this includes the tonnage below the Falls of Niagara.—Keep.

had become securely established. Chicago quickly took first place as a shipping point, its shipments increasing from 10 000 bushels in 1840 to upward of 28 000 000 in 1860. The present grain movement of the Lakes is about 200 000 000 bushels annually. In recent years, however, this movement, once the largest item in Lake commerce, has taken a place second in importance to iron ore from the Lake Superior ranges.

It is not generally known that canal communication was opened between Lake Superior and Lake Huron many years before the Erie Canal gave an outlet to Lake Erie. In fact, it was long forgotten that such a channel had ever existed. A few years ago, Judge Joseph H. Steere, of Sault Ste. Marie, a gentleman whose recreation has consisted largely of study of the history of former conditions in the Lake Superior region, found in some old records a mention of a canal and lock formerly existing on the Canadian side of the St. Mary's River at the rapids. He called to his aid a fellow townsman, E. S. Wheeler, M. Am. Soc. C. E., and they made jointly a search and were rewarded by finding the remains of this the earliest of the artificial waterways about the Great Lakes. It was built by the Northwest Company, about 1798, to facilitate the passage of *bateaux* engaged in the fur trade. Many canoes and sailing vessels have been run over the rapids since the white man first appeared on these waters, and the lives of passengers and crews cheerfully risked, but the consigning of valuable furs to such hazards was a more serious matter. The lock was 38 ft. long, 8 ft. 9 ins. wide, with a lift of 9 ft., which was about one-half the total fall at the rapids. The canoes and *bateaux* were assisted over the remainder by oxen. The lock served its purpose for several years but was finally destroyed by the Americans in 1814, during the war with Great Britain. A public-spirited resident of Sault Ste. Marie, Canada, has partially restored it, and gives it sympathetic care.

Soon after the full tide of immigration set in to the Lake region the Lake fisheries assumed prominence. Very soon the resources of Lake Superior in this direction attracted attention, and better communication with the Lower Lakes was demanded. The St. Mary's Rapids, with a fall of about 18 ft. in a distance of less than a mile, formed the only serious obstruction for the vessels of the time, and attention had been called, to the necessity of a ship canal around the rapids, by the first

Governor of the State of Michigan, in his message to the first Legislature of the State, in 1837. The Legislature authorized a survey and appropriated $25 000 to cover the expense. The survey was made the same year, and plans prepared for a canal 75 ft. wide and 10 ft. deep, with locks 100 ft. long and 34 ft. wide. These dimensions were greater than had been adopted for any other canal in the country. The cost was estimated at $112 544. Financial difficulties prevented the State from undertaking the work, and Congress was repeatedly but vainly besought to undertake it. In 1840 a bill was before Congress granting the State 100 000 acres of land to aid in the construction of such a canal. It was advocated mainly on the ground that it "would stimulate the fisheries of Lake Superior, estimated to be worth $1 000 000 per annum"; and, it was incidentally added, "in the country bordering the southern shore of Lake Superior copper ore and other minerals are believed to exist in abundance." While the bill was before the Senate, "Mr. Clay, of Kentucky, took occasion to speak of the work as beyond the range of the remotest settlements in the United States, or in the moon." Possibly the great senator, in preventing the inauguration of the work on a ridiculously inadequate scale, performed not the least of his many public services.

The existence of copper in the country adjacent to Lake Superior was known from a very early day, and was mentioned by Lagarde in a book published in Paris in 1636.* Other references soon followed. A more detailed account was given by Charlevoix, in the report of his journey made in 1721. Captain Jonathan Carver, whose voyage in 1766 has been mentioned, stated:

"The Ontonagon River is remarkable for the abundance of virgin copper on and near its banks, a metal which is met with also in several places on the coast. I observed that many of the small islands, particularly those on the eastern shores, were covered with copper ore."

"His book was, justly perhaps, regarded by many as a second edition of 'Gulliver's Travels,' and subsequent explorations failed to confirm the truth of many of his statements, which appear to have been merely the creations of a vivid imagination."

Another traveler, Alexander Henry, reported that he saw copper on the banks of the Ontonagon River in 1765, and, on a second trip to

*See "History and Review of the Copper, Iron, Silver, Slate and Other Material Interests of the South Shore of Lake Superior," by A. P. Swineford, Marquette, Mich., 1876.

the same locality, cut off from a large mass with an axe a portion said to weigh 100 lbs. A company was formed soon after, of which Henry was a leading member, to prosecute copper mining, a sloop built, as already stated, and miners sent to the site of the supposed mine. After one or two years of struggle at this site and at others, the enterprise was abandoned and little was heard of the mineral wealth of the Lake Superior region for sixty years or more.

One of the earliest measures taken by the State of Michigan, after its admission to the Union, was to provide for a geological survey. The work was placed in the hands of Dr. Douglass Houghton, one of the leading geologists of his time. He had already, in 1830 and 1831, visited the site of Henry's mine on the Ontonagon River, and again did so in 1840 while making his first geological survey. His reports "cleared up the mists of tradition, and attracted the attention of the people of the United States and of Europe to the new mineral fields."* In 1845 he fell a victim to the fury of the lake. His work resulted in the organization of numerous companies for mining copper. The first miners to visit the region after Henry's party in the previous century, went up the Ontonagon River in 1846 to remove the copper rock, which they succeeded in doing and in selling. It had been removed from Government land without license, and therefore was seized and taken to Washington where it is believed to still remain. During the same year mining under proper licenses was commenced at several sites, and the mining interests became at once a more potent influence than the fisheries, for better communication with the Lower Lakes.

It would be difficult to determine now whether copper or iron was the more powerful factor in securing such improved communication. Rumors of the existence of iron ore had been heard before its discovery by white men. They were placed on an authoritative basis by William A. Burt, Deputy United States Land Surveyor, the inventor of the solar compass. In September, 1844, he was engaged with a party in making land surveys, for the United States Government, in the region since known as the Marquette District. They began to notice remarkable variations of the magnetic needle which changed rapidly as they moved from place to place. Finally, they came to a place where the north end of the needle pointed south of west, and all hands stopped work and looked about for the cause;

* Swineford.

soon they had collected from outcrops numerous specimens of iron ore. The first iron mine in the district was located the following year, and in 1846 the first iron from Lake Superior ore was made in a blacksmith's forge. The first shipment of ore from Lake Superior was made in 1850 and consisted of 5 tons. No great development could be made without continuous navigation to the Lower Lakes; yet the impulse for better communications had resulted in navigation on Lake Superior itself on what may be considered a commercial scale.

A notable event had occurred in 1839, when *The Algonquin*, a schooner of 50 tons, was hauled overland past the rapids, and launched in Lake Superior. The development of copper mining furnished the impulse for repeating the feat, and several sailing vessels made the transit in 1845. In the same year the propeller *Independence*, 280 tons, was hauled over, and other steamboats followed; small sailing vessels could not compete with them advantageously, and several were run over the rapids to end their days in the Lower Lakes. In 1852, two steamers and four propellers were reported as employed on Lake Superior. Goods, arriving at Sault Ste. Marie from either direction, were unloaded, transferred by teams and wagons or by tram cars past the rapids and reloaded on vessels. The cost of this was too great to be borne by any but valuable articles, and, while copper could bear the expense, the shipment of iron ore was impracticable. In 1850 the total shipments across the portage were 6 000 tons. These were largely increased during the next four years immediately preceding the opening of the St. Mary's Falls Canal.

As often the case in later days, when a project of harbor or river improvement of questionable merit is pressed in Congress, a survey of the proposed St. Mary's Falls Canal was ordered, while an appropriation for the project itself was refused. From this resulted a better understanding of the commercial requirements and of the probable cost, and in 1852 Congress granted to the State of Michigan 750 000 acres of public land, requiring that the canal should be at least 100 ft. wide and 12 ft. deep, with locks at least 250 ft. long and 60 ft. wide. The lock dimensions were wisely increased to 350 x 70 ft. before construction began, there being two lifts of 9 ft. each. These dimensions were greater than in any other artificial waterway on the continent, if not in the world. Congress allowed three years for beginning the work and ten years for completion.

The State at once made arrangements with a corporation known as the St. Mary's Falls Ship Canal Company for building the canal for the land grant. The undertaking was, for the times, stupendous. The locality was almost as uncivilized, the resources of the surrounding country were almost as undeveloped, as when white men first set eyes upon it two centuries before; but the work was in the hands of able men, and notwithstanding the isolation of the place, and, at the outset, the utter lack of labor, machine-shops and all other facilities, and notwithstanding an outbreak of cholera which decimated the force, the work was executed in two years, and opened to commerce by the State on June 18th, 1855. The period allowed by Congress for beginning sufficed for its triumphant completion. Its cost to the constructing company had been, in round numbers, $1 000 000.* An amount of land equal to that granted by Congress could have been bought at the lawful rates for less money, but the Ship Canal Company had the valuable privilege of selecting lands not yet thrown upon the market, and this privilege they exercised with great wisdom and great good fortune. A notable example was the site of the famous Calumet and Hecla copper mine.

The building of the canal marked a stage in the development of Lake commerce hardly less important than the opening of the Erie Canal, thirty years before; not only because of the traffic through it, which, indeed, increased slowly, for the country about Lake Superior was still a wilderness and there were no great wheatfields beyond it, but because it fixed for many years the depths to be obtained in the harbors and in the channels connecting the Lakes, and, consequently, to a large extent, the dimensions of vessels and the cost of transportation. The depth of water in but few of the Lake harbors was as much as 12 ft., while in the channels connecting the Lakes there were serious obstructions. In the St. Mary's River a channel several miles long had to be dredged before the limited commerce to and from Lake Superior could make use of the full draft provided at the canal; while the St. Clair Flats interposed a like obstacle to the far greater commerce passing there. The Civil War soon absorbed the energy of the country, and other interests were secondary.

At the close of the Civil War the principal articles transported by water were grain and lumber. The receipts of grain and flour at Buf-

* $999 802 46.

falo in 1866 were about 1 500 000 tons; the receipts of lumber at Chicago alone were about 1 400 000 tons by Lake, while the iron ore shipments at all Lake ports were less than 300 000 tons, and the coal tonnage but a little greater than that of iron one. A more liberal policy toward internal improvements was then adopted by the General Government, and projects for harbor and channel depths of 12 ft. were prepared and soon executed. This depth sufficed for only a few years. By 1870, or soon after, vessels drawing 13 ft. and upward could enter a few of the more important ports, such as Buffalo, Cleveland and Chicago, and a demand for a depth of 16 ft. became general. The initiative was again taken at the St. Mary's Falls Canal by a project for increasing the depth from 12 to 16 ft. and building a new lock, 515 ft. long and 80 ft. wide, overcoming the entire difference of level of about 18 ft. by a single lift. These dimensions were unprecedented in canal construction. A distinguished professional visitor from the other side of the boundary declared, with something like indignation, that this was not a canal lock but a basin. The Welland Canal was then being enlarged, with locks 270 x 45 ft. and about 14 ft. lift. The lift of 18 ft. was almost universally criticised as unprecedented and injudicious. The improvement begun in 1870 was completed in 1881, at a cost of $2 200 000, but, before the increased depth could be made fully available, the St. Mary's River had to be deepened in numerous places, the St. Clair Flats Canal dredged and a cut made through a reef of rock near the mouth of the Detroit River. The last-named improvement was noteworthy by reason of the methods adopted for sub-aqueous rock excavation. The cost of the excavation had been estimated by a Board of Engineers at $30 per cubic yard, but the ingenious devices and methods of a single contractor resulted in a lowering of prices to $7.00. Similar work has since been carried out at one-third of this figure with large profit.

The 16-ft. channel was completed in 1884. In the meantime the principal harbors were put in readiness and a fleet of large vessels was built to take full advantage of the new facilities. The growth of traffic had been notable. The average annual receipts of grain at Buffalo had increased above 50 per cent. The shipment of coal by Lake at the beginning of the period was almost nil; at the end it was 3 000 000 or 4 000 000 tons, or more than half the entire Suez Canal traffic. Iron ore shipments had increased from 300 000 tons in 1866 to 2 500 000 tons

in 1884. The number of vessels on the Lakes had increased but slightly, but the gross tonnage had increased about 50 per cent. Freight rates had fallen remarkably; on iron ore from Lake Superior to Lake Erie ports they had fallen from $3 to $1.35 in gold per ton, and on wheat from Chicago to Buffalo from 9 to 2¼ cents per bushel. The net registered tonnage through the St. Mary's Falls Canal had increased 440 per cent.

Before the project for a 16-ft. navigation had been fully carried out, it was clearly seen to be inadequate, and measures were taken for increasing it. Largely through the foresight of a member of this Society, General Orlando M. Poe, now deceased, then in charge of harbor and river improvements between Lake Erie and Lake Superior, the new work was undertaken on a liberal scale. A depth of 19 to 21 ft. is now found in the principal harbors and in the connecting channels between the Lakes. A new channel was opened through the system of small lakes and straits known as the St. Mary's River, saving 11 miles in distance, and practicable for night navigation.

The extent of the improvements in the connecting channels is much greater than generally realized. Between Lakes Superior and Huron the aggregate length of new or deepened channels is 20.3 miles, and between Lakes Huron and Erie 21.2 miles. The commerce between Lake Superior and Lake Erie, aggregating 25 000 000 to 30 000 000 tons per year, passes through all of these, a total of 41.5 miles of artificial waterway. This is 5 miles greater than the length of restricted waterway to be made at the Panama Canal. The width of the Lake channels, however, is greater than now proposed for the Inter-oceanic Canal, varying from 300 to 1 000 ft., excluding a distance of about a mile at the St. Mary's Falls Canal, where the minimum width is about 115 ft., and a mile at the foot of Lake Huron, where the width is 2 400 ft.

These improvements included the deepening of the St. Mary's Falls Canal to 25 ft., and the building of a new lock, 800 ft. long and 100 ft. wide, with 20 to 22 ft. over the miter-sills, located on the site occupied first by the old State locks. It was opened to navigation in 1896. The cost of the Canal improvement was $3 800 000. This is the largest lock in existence, and, like its predecessors at the same place, was intended to pass three or four of the largest vessels at once. As in the previous cases, this expectation was not realized by reason of the rapid growth of ship dimensions.

While this lock was building, the Canadian Government decided to have a canal on their own side of the river, and built it at a cost of $4 000 000. The canal and lock give a depth of 22 ft. The lock is 900 ft. long and 60 ft. wide. It was opened to navigation in 1895. The lockage facilities at the St. Mary's Rapids now comprise three independent locks, each overcoming the entire difference of level at the rapids, and each equipped with hydraulic or electrical machinery for all operations. The last built American lock, opened in 1896, passes about 70% of the entire amount of commerce entering and leaving Lake Superior.

The amount of commerce passing through these improved waterways almost challenges belief. The Detroit River, undoubtedly, carries more tonnage than any other river or harbor in the world, the freight tonnage being estimated at 40 000 000 to 50 000 000 per year. St. Mary's River, with its freight tonnage of nearly 36 000 000 in 1902, may be the second. Of the leading articles transported, grain receipts at Buffalo increased nearly 300% from 1884 to 1898, the receipts there in the year last named being nearly 270 000 000 bushels,* or about 7 000 000 tons. The coal movement is somewhat greater, while the movement of iron ore is three or four times as much as either. Several lessons of importance, in the design of ship canals, are taught by experience with these waterways, which are peculiarly applicable to the project for an Isthmian Canal.

One of these lessons is that a very large traffic can be carried through a canal with locks. During the navigation season of 1895, embracing 231 days, a tonnage of 16 000 000 tons, net register, was passed through a single lock, the vessels averaging less than 960 tons each. During the last season, of 264 days, the net registered tonnage passed through the triple system of lockage was nearly 32 000 000 tons, the vessels averaging 1 410 tons; of this tonnage upward of 22 000 000 passed through one of the three locks. In the two months of July and August the tonnage through the St. Mary's Falls Canal was almost exactly equal to the tonnage through the Suez Canal during the entire previous year, allowance being made for difference in methods of measurement. With a twelve months' season of navigation, the triple lockage system at the St. Mary's Falls Canal would pass 50 000 000 to 60 000 000 tons without serious delay, in vessels of the

* Rept. Committee on N. Y. State Canals. 1899.

present average tonnage. If the average tonnage were doubled, making it equal to that of ships now using the Suez Canal, the capacity would be considerably greater. The most sanguine promoter of an Isthmian Canal would not expect this total to be reached in that waterway for a long time to come.

A second lesson is that a canal with locks operated carefully is a safe waterway, as far as the locks are concerned. It is not necessary to give the space to this consideration that its importance seems to warrant, for the proof can be summed in a single sentence. During the forty-eight years since the opening of the St. Mary's Falls Canal to navigation the stoppages at locks have probably not averaged two days per year, or one day for 3 000 000 tons passed. With locks in duplicate, the stoppages of navigation are almost nil.

The third lesson is the importance of a wide channel. The unfortunately narrow width adopted for the Suez Canal, only about half that originally intended, but made necessary to prevent the cost exceeding twice the estimate, has been a harmful precedent. It has been increased there, and will, doubtless, be further increased as traffic increases. In the channels connecting the Great Lakes, where 300 ft. width was generally first adopted for the 20-ft. navigation, the width is being increased to 600 ft. or more, and the principle is adopted that the width of channel should be greater than the length of the largest ship. This principle may be considered applicable generally where currents are strong, the traffic great, and the cutting not too deep.

The improvement of the navigated channels has been accompanied by corresponding developments in the dimensions and character of vessels. Before 1870 the greater part of the freight movement was in sailing vessels carrying 300 to 600 tons. In 1872 appeared the first of a new type, consisting of fleets of two or more vessels, one propelled by steam towing the others, except when compelled by stress of weather to cast off lines. The vessels towed, called tow-barges, were sailing ships not fully rigged, but they could take care of themselves in a storm. The first of these were of 600 to 1 100 tons, net register, carrying in freight about twice the registered tonnage. As the opening of the 16-ft. channels drew near, larger vessels were built, and when that depth became available, in 1884, a great many of 1 500 to 1 900 tons, net register, were in use. The increase was most marked in steam vessels. Up to this time, and for several years

thereafter, while grain was the largest item of freight and Lake Michigan ports were the principal shipping points, the largest steamers were employed between Lake Michigan and Lake Erie. By 1888, iron ore had become the leading article, and from that time the vessels built for that trade were larger in tonnage and number than those for any other. During the period from 1888 to 1891, inclusive, the ruling type of freight vessel turned out from the shipyards was of 1 500 to nearly 2 000 tons, net register, carrying 3 000 to 4 000 tons on a draft of 14 to 15 ft. Few sailing vessels or tow-barges were built during this period, except in a single class, the well-known "whale-backs," more generally called "pigs," which, when fully laden, they much resemble. The first of these appeared in 1889. They ran in fleets, one steamer towing one or more barges. They were economical to build and were great carriers, but have not proved altogether successful, and no more are building. By 1892 the preponderance of iron ore, as the leading article of Lake commerce, had become established, and from that year the building of ships for this trade has been the leading feature of Lake ship-building. The near approach of a 20-ft. navigation stimulated each year the building of larger ships. More than half the tonnage of freight-carrying vessels built in 1896, when the last American lock was opened to navigation, was in ships exceeding 2 000 tons, net register. Six years before, not a single vessel of this tonnage was in service. The largest vessels yet put in service were built in 1900. Their net registered tonnage is about 4 500 each, but they carry nearly twice their net register. They are 498 ft. long, over all, and of 52 ft. beam. During the last three years there has been a marked tendency to smaller dimensions, but contracts are now placed for still larger vessels. The building of sailing ships has practically ceased. The tonnage built on the Lakes during 1902 was 158 230 tons in 104 vessels, an average of 1 521 tons; while that on the Atlantic and Gulf Coasts was 214 538 tons in 856 vessels, an average of 251 tons, or about one-sixth as much. A comparison of steel steam vessels is perhaps more just. Such a comparison shows: For the Lakes, 44 ships of 152 267 total tonnage, or an average of 3 461 tons; and for the seaboard, 62 ships of 128 571 tons, or an average of 2 076, the Lake tonnage being 18% greater in amount and the vessels 66% greater in average capacity.* The total tonnage on the Lakes is a little more than one-third of the total of that of the United States.

* *Marine Review*, January 8th, 1903.

The freight on the Lakes consists mainly of a few items, and facilities for handling them have reached a greater degree of efficiency than anywhere else. Iron ore is loaded from pockets in lofty piers and falls directly into the hold of the ship. The ore piers have now a storage capacity of nearly 1 000 000 tons. During the last season a ship received its full load of 5 290 tons in 68 minutes, through nineteen hatches. The equipment for unloading is almost equally perfect, a cargo of 5 300 tons having been unloaded in 3 hours and 45 minutes. Coal is loaded from cars at the rate of 1 000 tons per hour. The use of elevators in loading and unloading grain, mainly a development of Lake commerce, is too well known to need further reference.

It should not be understood that these periods represent averages, or define the stay in ports. Ore-carrying ships require from one-half to one day in the receiving port and about three days in the discharging port, getting a dock and unloading; coal-carrying ships require about one day more at each end of the route. Grain ships require about one day in the receiving port and two in the discharging port.* There is still room for improvement in port facilities.

The most remarkable feature of Lake commerce is the marvelous development of the mining and shipment of iron ore. In 1888 it exceeded 5 000 000 tons for the first time. It doubled in the next seven years and again doubled in the next six years, passing 20 500 000 tons in 1901. In that year the Lake Superior mines furnished 74% of the entire amount produced in the United States. In 1902 the output was increased by 7 000 000 tons, making a total of 27 500 000 tons, which was equal to the total output during the thirty years from the first shipment to 1885, while the increase alone was greater than the entire output of any year previous to 1889. While the output in the United States at large doubled between the years 1888 and 1901, the production of the Lake Superior mines quadrupled during the same period, furnishing nearly all the increase in the ore production of the country.

This wonderful development of a few leading articles of freight has resulted in cheaper transportation than known elsewhere, except on long ocean routes. The most reliable and complete data existing are obtained at the St. Mary's Falls Canals by the co-operation of the Governments of Canada and the United States. The average freight

*Information in regard to delay in ports was furnished by Captain George P. McKay, Treasurer, Lake Carriers' Association; and by the Editor of the *Marine Review*.

rate on all classes of freight during 1902 was 0.89 mill per ton-mile, the average haul being 827.4 miles. If the freight had been carried by rail the average rate could hardly have been less than 3 mills per ton-mile, and the average haul would have been about the same as by water. On this basis the saving in transportation by the water route during one year was nearly $63 000 000. This amount of saving on Lake Superior commerce alone, during a single year, is within $5 000 000 of the entire amount appropriated by the United States for all harbors and waterways on the Lakes above Niagara Falls from the formation of the Government; if the commerce between Lake Michigan and Lake Erie be included, the annual saving greatly exceeds the amount thus appropriated. Indeed, the saving during one year on a single article, iron ore, would repay all the money expended up to this time on the waterways and harbors which it traverses on its way from mine to furnace. Viewed in this way, no great investment was ever made by a corporation or government with such a magnificent showing of profit. But a far broader view may be taken justly; this water route has not merely afforded a saving in expense of transportation, but has been creative of a large part of the wealth of the nation. Without it the development of our manufactures of iron and steel and other industries dependent on them or related to them, all constituting a great share of the national wealth, would have been retarded or impracticable; without it the prairies of the Northwest would have remained unproductive and unpeopled for a much longer time. With these broad considerations in view we may place to the credit of Lake transportation a sum perhaps hardly definable, but compared to which the largest above mentioned is a mere trifle.

It must not be assumed that the minimum freight rates for a 20-ft. navigation have yet been reached. Taking iron ore as an example, the average rate for the year 1902, 0.68 mill per ton-mile, was based on unusually high expenses for labor and other items; moreover, the full channel depth, provided for under the present project for harbor and channel improvements, is not yet fully attained. In the Detroit River the average limiting depth is only 19 ft., instead of 20 ft., as intended. The addition of another foot will permit an increase of cargo, in the largest ships, of about 10%, with little increase in cost of transportation. With normal expenses, larger cargoes and further improvements of terminal facilities, a large reduction of freight charges will be certain to occur.

From the study of Lake navigation, some general principles governing cheap transportation may be deduced, which will be applicable to other places.

1.—For the cheapest water transportation there must be adequate depth in the channels, so that large ships can be used. Freight rates on iron ore from Lake Superior to Lake Erie ports were, during prosperous years, about $2 per ton when the limiting depth was 15 ft. and less than $1 with the present limiting depth of 19 ft.

2.—There must be adequate facilities for handling cargo, so that the delay in port may be reduced to a minimum. The Lake ports have probably the best facilities existing anywhere, and these are important factors in the low freight rates which obtain, notwithstanding the facts that the vessels lie up 4 or 5 months during the year, and, during the season of navigation, make short voyages compared with sea-going ships. Ore-carrying ships make twenty to twenty-four round trips during the season of seven to eight months, or a mileage of 32 000 to 40 000 miles. The average speeds are 10 to 12 miles per hour. During the last season a ship of somewhat higher speed made 45 340 miles.

3.—Different classes of freight require different rates of speed. Lake ships carrying package freight, some of it perishable, some of high value, run 12 to 14 miles per hour, but for those carrying ore a speed of 10 to 12 miles has been found more economical, conforming closely to the usual speed of tramp ships on salt water.

4.—Transhipment must be avoided as far as possible. The Erie Canal, with its 7-ft. navigation and transhipment at Buffalo, has shown a steadily decreasing business in the transportation of vegetable foods, and in 1900 carried only one-third as much as 1869, and only one-fifth of the amount in the maximum year, 1880. The Welland Canal has barely held its own during the same period, although its depth has been increased from 9 to 14 ft. The New York Central and Erie Railroads increased their tonnage in this class of freight six times during the same period. The 14-ft. navigation of the St. Lawrence to Montreal, completing this navigation from the Lakes to tide-water and to sea-going ships, has been opened too recently to predict its consequences safely. It still lacks the necessary terminal facilities at Montreal, but neither this lack, nor the hazardous navigation of the Lower St. Lawrence, from Montreal to the Atlantic, has prevented a great increase in the receipts of grain at Montreal by rail.

5.—The prime requisite, after all, for cheap transportation is the existence of great natural resources in the tributary districts. So much misleading discussion of the benefits of water routes has been indulged in, in recent years; such broad inferences have been drawn from the traffic through the St. Mary's Falls Canals as to results to be expected from the opening of other waterways, that it seems necessary to state this truism seriously. The freight tonnage through these canals consists almost entirely of a few articles; first of these is iron ore, which in 1902 was 67% of the total; next is coal, 13%; then flour and grain, 10%; then lumber, 6%; these four articles making 96% of the total. In the natural course of events the iron ore and lumber will be exhausted; but for their accidental and temporary existence, the traffic would not be more than 27% of its present amount; and doubtless even less than this because the development of these two articles has powerfully promoted the development of others. The lumber shipments will soon diminish and before many years will practically cease. Ore shipments will reach a much higher amount than the present before the decline, which is inevitable, sets in. In the meantime the shipments of coal and of agricultural and manufactured products will increase, and, possibly, after the exhaustion of the ores, the traffic may remain as large as at present or even become much greater. However this may be, it is clear that the present development is due to a combination of agricultural and mineral resources not found anywhere else in the world, and to a spirit of daring enterprise and restless energy hardly paralleled in the history of industrial effort.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 951.

A SMALL ROCK-FILL DAM.*

By H. de B. Parsons, M. Am. Soc. C. E.

With Discussion by Messrs. Samuel H. Lea and Foster Crowell.

The rock-fill dam described in this paper was designed by the writer for George Crocker, Esq., to impound a gravity water supply for his estate at Darlington, near Ramseys, New Jersey.

The site selected was at the head of a ravine where the hills widened out, forming a natural bed for a lake. The site was about 250 ft. above the farm buildings in the valley of the Ramapo River, and about 65 ft. above the point selected for the new residence.

The small brook running down the ravine had a probable summer average flow of from 9 to 10 cu. ft. per second. During extreme freshets, this flow was increased rapidly, probably to sixty or seventy fold, as, owing to the rocky formation of the hills in this locality, the run-off and rainfall are nearly equal.

A dam height of 20 ft. was decided upon as being sufficient to impound about 11½ acres of lake surface. The length along the crest was 235 ft.

Rock outcropped on the east side of the brook, but disappeared on the west side. Test pits dug on the latter side showed the covering to consist of: Gravel and soil, 1 ft. 6 ins.; mixed sand, gravel and

* Presented at the meeting of May 6th, 1903.

clay, 9 ft. 6 ins., and blue clay beneath. The outcropping rock was found to be seamy and somewhat broken. The approach to the site, by road, was difficult, due to the steep incline. The problem, therefore, was the design of some form of dam which would be easy to erect and would require the least amount of falsework or contractor's apparatus.

Under the foregoing conditions it was decided that a rock-fill dam, backed with earth on the water side, was the most expedient. Furthermore, the cost of such a dam was estimated to be less than one-third of the cost of a masonry dam of equal size.

The general plan and down-stream elevation are shown in Fig. 1, the cross-section in Fig. 2, and the gate-house in Fig. 3.

The rock on the east bank was blasted out, so as to provide a foundation for the gate-house, and the surface rock was prepared to receive the rock fill. All seams and cracks in the rock were pointed carefully with Portland cement.

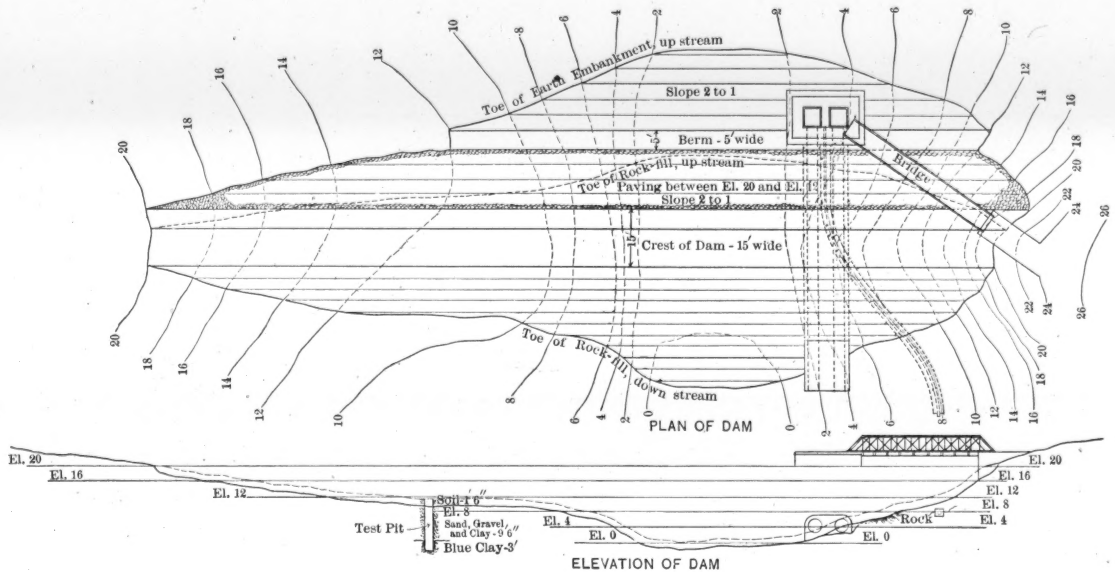
The earth and soil, for a depth of about 18 ins., were removed from the site of the dam between the up- and down-stream toes. A trench, about 30 ins. deep, was then dug along the up-stream toe, and a double row of sheet-piles, with lapped joints, was driven. These piles were 3 ins. thick, and were driven until rock was reached or the end entered the blue-clay stratum. In no place did they exceed 14 ft. in length.

The gate-house and blow-off pipes were then constructed. The gate-house was built of rubble masonry, laid in Portland cement mortar consisting of 1 unit by measure of cement to $2\frac{1}{2}$ units of sand. The grooves for the gates and screens were six-hammered. The top was finished with a cut-stone coping, filled flush at the center with concrete.

The blow-off pipes were 36 ins. in diameter, and were of steel, $\frac{1}{4}$ in. in thickness, stiffened every 10 ft. by 3 x 3-in. angles, which also acted as water stops. The sheets were single-riveted and caulked. These pipes were bedded in concrete, which was tamped closely under and around them.

Ridges were left in the concrete to act as water stops and to hold the rock fill and earth in place.

When sufficient work had been accomplished on the gate-house and blow-offs, the rock fill was commenced. By thus regulating the



ROCK-FILL DAM
AT
RAMSEYS, NEW JERSEY
FOR
GEORGE CROCKER, Esq.

Scale of Feet
0 10 20 30 40 50

FIG. 1.

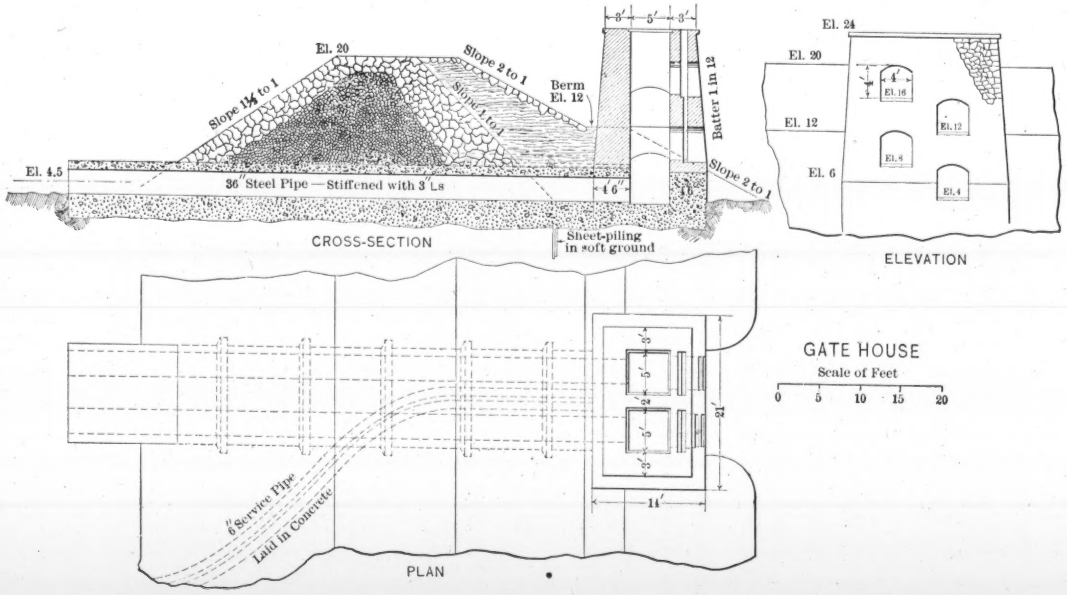

El. 20
Slope 2 to 1
Slope 1¼ to 1
Slope 1 to 1
Berm
El. 12
El. 4.5
36″ Steel Pipe — Stiffened with 3″ Ls
4′ 6″
Batter 1 in 12
Slope 2 to 1
CROSS-SECTION
Sheet-piling in soft ground
El. 24
El. 20
El. 12
El. 6
El. 16
El. 8
El. 4
ELEVATION
GATE HOUSE
Scale of Feet
0 5 10 15 20
6″ Service Pipe Laid in Concrete
14′
PLAN

FIG. 2.

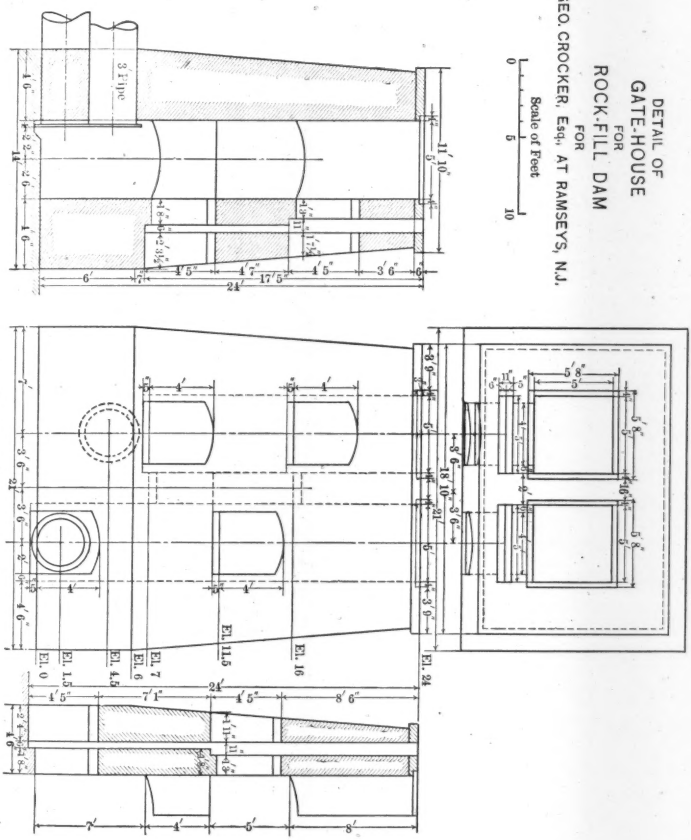

DETAIL OF
GATE-HOUSE
FOR
ROCK-FILL DAM
FOR
GEO. CROCKER, Esq., AT RAMSEYS, N.J.
Scale of Feet
0
5
10
3' Pipe
El. 0
El. 1.5
El. 4.5
El. 6
El. 7
El. 11.5
El. 16
El. 24

Fig. 3.

work, the brook was allowed to follow its natural course until the rock fill began to dam it up, when the water was passed through the lower of the blow-off pipes. The work could thus be carried on from beginning to end in a dry state and without the use of coffer-dams or other falsework.

The rock fill was made from stone, blasted out of the hillside, loaded on wagons and simply dumped on the work. Care was taken to build up the wall in horizontal layers, and to use a sufficient quantity of small stones and spawls to fill the voids as full as possible. The stone carts were driven over the work as it progressed, in order to help jar and pack the stones. The stones were all cleaned carefully before being put into the wall; and, in shape, were rough and jagged, all smooth stones being rejected.

The best-shaped stones were reserved for hand placing on the two faces. On the down-stream face, the hand packing was about 5 ft. thick, and on the up-stream face from 5 ft. at the crest to 10 ft. at the toe. This hand packing resembled dry rubble masonry, and was carried up a little in advance of the center filling. Its object, on the up-stream face, was to help make the dam water-tight by offering narrow and broken joints, which would retain the matter carried in by leakage. On the down-stream face, the object was to permit the dam to overflow without material injury. No spillway was provided in the crest, because the dam was intended to be used as a driveway during the summer season. It is only at rare intervals that the dam is expected to overflow, and the long crest will allow ample way for the water, which will not be more than a few inches in depth on the crest, even at periods of worst flood. Such floods last only a short time. Should injury be done by ice or overflow, the damage can be easily repaired.

The earth fill consisted almost entirely of clay, which, luckily, was more abundant than had at first been anticipated. It was carried up in horizontal layers, about 6 ins. in thickness, and each layer was well watered and rolled with a grooved two-horse roller. The water side was paved above the berm with flat stones, laid so as to have an average depth of 12 ins. This was done as a protection against ice.

At the east end of the crest, a rubble stone abutment was built, and a light, steel-truss bridge extended to the top of the gate-house.

The water service pipe was of lap-welded, wrought iron, 6 ins. in diameter, with the lengths joined by heavy flanges, having faces turned true, and bedded in the concrete mass with the blow-offs.

FIG. 1.—PROGRESS OF WORK, JULY 1ST, 1902.

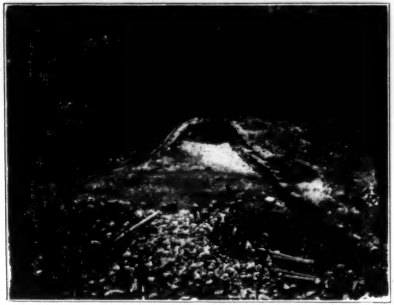


FIG. 2.—PROGRESS OF WORK, AUGUST 1ST, 1902.

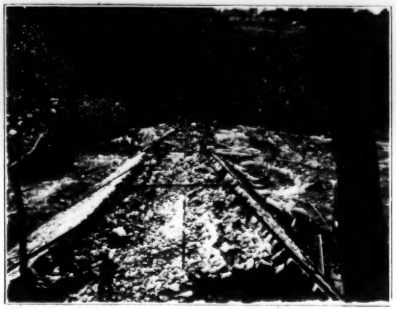


FIG. 3.—PROGRESS OF WORK, SEPTEMBER 11TH, 1902.

FIG. 4.—PROJECTING ENDS OF BLOW-OFF PIPES.

The work was commenced on May 21st, and completed on November 8th, 1902. When finished, the dam was practically water-tight. There was a slight leak at the lower of the blow-off pipes, but this diminished in volume rapidly, and ceased in about thirty days.

Fig. 1, Plate XXXIV, shows the progress of the work on July 1st. The cut-off trench for the sheet-piling is seen on the left, and the blow-off pipes in the back-ground.

Fig. 2, Plate XXXIV, shows the progress of the work on August 1st. The sheet-piling is seen clearly on the right, and the rock fill in the foreground.

Fig. 3, Plate XXXIV, shows the progress of the work on September 11th. The construction of the dam is seen in this photograph. The hand-placed material on both up- and down-stream faces, with the loose rock fill in the center, is easily distinguishable.

Fig. 4, Plate XXXIV, shows the down-stream ends of the blow-off pipes embedded in the concrete and projecting through the dam. The photograph also shows the character of the hand-placed work.

Fig. 1, Plate XXXV, shows the progress of the work on October 21st. The commencement of the earth embankment will be noticed on the right.

Fig. 2, Plate XXXV, shows the gate-house structure on October 21st.

Figs. 3 and 4, Plate XXXV, show the completed structure, with the pond about half full.

The dimensions of the dam are:

Length on crest	235 ft.
Height at center	20 "
Width of crest, total	15 "
" " " masonry	10 "
" " " earth	5 "
Slope of masonry, up-stream face	1 on 1
" " " down-stream face	1 on 1½
" " earth embankment	1 on 2

The contract price was $8 700.

The quantities, and a close estimate of the unit prices, are given in Table No. 1. These unit prices include all the contractor's expenses, but not his profit, as the work appeared to cost all of the contract price.

TABLE No. 1.

Item.	Quantity.	Unit Price.
Earth excavation	794 cu yds.	$0.30
Earth embankment, including rolling	1 257 " "	0.43
Rock excavation	210 " "	1.60
Rock fill, core filling	1 642 " "	0.45
Rock fill, hand-packed	1 353 " "	0.95
Timber, sheet-piling	13 200 ft. B. M.	54.00
Timber, gates, bridge floor, etc.	1 200 " "	80.00
Concrete	120 cu. yds.	7.80
Paving	142 " "	1.70
Rubble masonry	157 " "	8.10
Fine-hammered facing	136 sq. ft.	0.80
Steel bridge	3 000 lbs.	0.10
Blow offs and service pipes	16 150 "	0.10
Gate-valves, two 36-in. and one 6-in.	3	220.00
Hand-power winch	1	40.00

The contractor was Mr. Watson E. De Baun, of Tuxedo, New York, to whom, and to Mr. James White, his foreman in charge, credit is due for the faithful way in which they carried out the intent of the specifications. The writer also acknowledges his thanks to William A. Cattell, M. Am. Soc. C. E., for some suggestions, and to H. B. Atkins, Assoc. M. Am. Soc. C. E., and Mr. John W. Doty for their supervision of the construction.

FIG. 1.—PROGRESS OF WORK, OCTOBER 21ST, 1902.

FIG. 3.—THE COMPLETED DAM.

FIG. 2.—THE GATE-HOUSE ON OCTOBER 21ST, 1902.

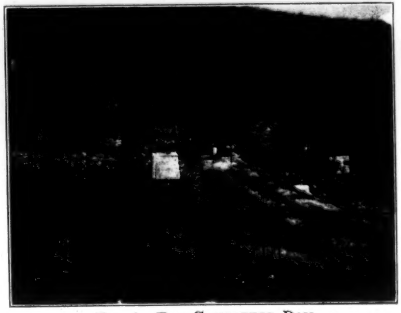


FIG. 4.—THE COMPLETED DAM.

DISCUSSION.

SAMUEL H. LEA, M. Am. Soc. C. E. (by letter).—The writer is unable to see the advantage in hand-packing the up-stream portion of the rock fill. The author states that the object was to help to make the dam water-tight by offering narrow and broken joints which would retain the matter carried in by leakage. This reason would have considerable weight if the up-stream face of the rock fill had been left exposed and free to receive the full volume of silt and suspended matter contained in the water. As the dam was backed with earth on the up-stream side, the only matter that could be carried into the rock fill would be from the earth fill. This fill is stated to consist almost entirely of clay, an impervious material allowing little or no leakage. Mr. Lea.

The writer thinks the hand-packing of the up-stream face of the rock fill rather a disadvantage, except in the respect that the portion thus packed would naturally be of greater solidity and would consequently afford greater stability to the structure. This effect could have been obtained by building the up-stream portion of the rock fill with a slope of $1\frac{1}{4}$ to 1 and placing the stone without hand-packing. This proceeding would have required an additional quantity of stone, but the cost of the extra stone would have been more than compensated for by the smaller unit cost of the stone in place and by the decrease in the yardage of the earth fill.

As constructed, the rock fill and the earth fill meet in a comparatively smooth surface, affording no chance for a bond or connection between the two substances. This surface constitutes, in effect, a plane of weakness, which is likely to become a sliding plane if storm, water or flood-water uses it as a channel or duct. Should this occur the displacement of parts of the earth filling nearest the rock might follow, and this would cause settlement in the earth fill. If the slope suggested by the writer—$1\frac{1}{4}$ to 1—had been used, and the earth nearest the rock had been well tamped into the interstices between the stones and the irregularities of the surface, a good bond would have been formed between the earth and rock fills and the liability to slip thereby lessened. In addition, the danger of the penetration of storm-water or flood-water would have been minimized.

If preferred to have the up-stream face of the rock fill hand-packed, it would have been better to have finished it in steps. The earth filling next to the stone could have been selected clay carefully tamped. A good bond would thus have been formed. The author does not state whether the cut-off trench was connected with the dam in any manner to prevent seepage over the top of the sheet-piling. To insure water-tightness the trench should have been filled with clay well puddled, and the filling carried up over the face of the rock fill for a foot or more, joining the clay filling next to the rock fill.

Mr. Lea. In large rock-fill dams, constructed in the West, provision is generally made for water-tightness by special constructions, such as timber facing, steel diaphragms coated with asphalt, or by other methods.

The writer believes that the methods suggested by him will meet all requirements in the case of a small dam such as that under consideration.

Mr. Crowell. FOSTER CROWELL, M. Am. Soc. C. E.—This paper is very interesting, because, while the work it describes is very good construction in itself, it also serves as a model and attracts attention. It also suggests those measures of precaution which have to be taken in all structures with which water has to do, and against which the effects of water confined have to be guarded.

In reading the paper the speaker has been reminded that the great difficulty in all dams is the connection of the structure with the natural formation, and guarding against the escape of water through the latter, which may either endanger the structure or simply draw upon and waste the needed water supply.

Some time ago, in constructing a dam in Michigan, the speaker was obliged to take some extraordinary precautions because of the insecure character of the natural formation, and it might be instructive to note one particular expedient adopted.

The dam referred to was about 80 ft. in height, and about ¼ mile in length on the crest. It was built across a cañon, and at its deepest part was founded in stratified rock, which formed the river-bed. The rock walls of the cañon had been cut out by the stream in times past, and its bottom was very much broken up and eroded by the action of the water. The stratification was almost horizontal, dipping slightly down stream, and the interstices or separations between the different planes of the rock permitted the entrance of water, which, under a head, would have a wedge-like effect, with the result of splitting or bursting the rock in large masses. Across the cañon, and further up stream, there was an older and lower dam which the new one was to replace. The former was an overflow dam, about 60 ft. in height. Through successive seasons, the water, in times of freshets, in passing over this dam, had eroded in the rock formation a large cave, about 13 ft. in depth and 30 ft. in length, extending from the toe of the old dam. This had been guarded by a timber apron, but the destruction had gone on, and, in fact, it was the impending destruction of the old dam which led to the construction of the larger one. The splitting action of the moving water under pressure had broken off, lifted and carried away the rock from this hole, and it was quite common after a freshet to find large masses of rock, which had been split off, turned over and carried some distance down stream.

When the new dam was built, its foundations, of course, were carried into the same formation, and, as it was important to protect

the rock under the dam from the continuation of such action, various plans were considered as to how the flow of water through the formation could be effectually stopped without going to very considerable expense, or carrying the dam down below a reasonable depth. Mr. Crowell.

It was supposed, too, that the water probably had gone through the formation, and had made some underground opening for itself, and that, unless effectually guarded against, the action might continue and cause serious water loss, or destroy or impair the new dam.

About 25 ft. up stream from the up-stream face of the new dam a row of 2½-in. holes was drilled vertically in the rock. These holes were about 7 ins. apart, from center to center, which was about as close as experience showed that they could be drilled without breaking the rock between them. The row extended across the whole width of the cañon and into its sides. The holes were drilled to a depth of about 10 ft. below the lowest point reached by the seal under the new dam, and were filled with Portland cement grout under a pneumatic pressure of about 90 lbs. Subsequently, the entire rock surface from the heel of the dam to just beyond the row of holes was covered with concrete. The holes were filled successively from the ends toward the center; that is, beginning at one side, and filling them one by one, out nearly to the center, and then beginning at the other side. Finally, all the holes but one were filled, and at that time an interesting incident occurred.

During the progress of the work the flow of water, which was very great, was carried over the work by means of a large flume, built for the purpose from the crest of the old dam, so that it was only necessary to remove, by continuous pumping, such water as percolated through the old dam or overflowed into the cañon from the flume, and a pump discharging through an 8-in. pipe was generally sufficient to keep the work dry. During freshets the pump was drowned out. This occurred at the time when all the holes but one had been filled with grout, and the water rose a few inches ever the top of the holes.

The theory on which the holes were drilled was that the stratification would extend from hole to hole, and, therefore, if there was any opening in the formation through which the water could pass down stream, such opening would exist between the holes, and the grout, in that case, would be forced from one hole to the other under pressure and form a diaphragm across the formation. Therefore when all the holes except this last one had been filled with grout, and the flooding occurred, air pressure was applied to the unfilled hole, and it was thought that if the operation had been successful no air bubbles would be found coming up on the line of the holes on either side, but only up and down stream from the last hole. This proved to be the case. A very copious escape of bubbles took place both up and down stream

Mr. Crowell. from this last hole, but none at all on the line of the holes. The day afterward the water went down. The last hole was then filled with grout and the water allowed to cover the holes again, and when air pressure was applied to the last hole there was no escape of air in any direction.

That was a satisfactory demonstration that an absolute seal across the formation had been secured, and, of course, if it was absolute, though only 2½ ins. in thickness, it was just as good as if it had been a large and heavy structure, and probably better. The result was that, when the water was turned on, the stream below, which was quite a large river, became absolutely dry; and there never was any appearance of seepage or leakage at the bottom of the dam until the water had reached a head of about 57 ft.; but when it came above that level it was noticed that a very small leak had started somewhere on the shoulder at one end of the dam, in the formation. Great care had been taken to secure proper connection between the ends of the dam and the flanks of the rock, but, possibly, the work was not done as thoroughly as in the other case.

This small leak made its appearance on the down-stream face of the structure, and by experimenting it was found that it entered the formation nearly 100 ft. up stream. The place of entrance was detected by raising and lowering the water, which was under full control by means of a system of discharge pipes. It was found that, whenever the water reached a certain contour in the formation, air began to escape from below ground at one point, and the leak would then appear below the dam, or coming out through the dam on the side. The leak was a matter of no importance; it could all be taken care of through a small pipe, and its velocity was very slight. It was only interesting as showing that it was possible for leaks to take place through a formation of that character in a very unexpected direction, and emphasized the necessity of being absolutely sure that the connection between a dam and the natural formation is such as to prevent any escape of water between them.

The other problems of dam design—the strength, weight and stability, through its form—are academic. It is generally quite easy to design all those features, but it is difficult to make sure that the dam is absolutely connected to the natural formation, and that all percolation and all flow through the latter have been prevented.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 952.

THE ECONOMIC IMPROVEMENT OF THE COOSA AND ALABAMA RIVERS, IN GEORGIA AND ALABAMA.*

By D. M. Andrews, M. Am. Soc. C. E.

With Discussion by Messrs. R. R. Raymond and D. M. Andrews.

The Coosa River is formed by the junction of the Oostanaula and Etowah Rivers at Rome, Ga., which streams have their sources in the mountains of Northern Georgia.

The Oostanaula and its tributary, the Coosawattee, are navigable the year round for light-draft boats from Rome, Ga., to Carter's Landing, a distance of 105 miles.

The Coosa has always been navigable from Rome, Ga., to Greensport, Ala., a distance of 162 miles. From Greensport to Lock No. 4, Ala., a distance of 26 miles, the river has been made navigable for boats of 4-ft. draft by the construction of three locks and four dams, and by channel excavation at points between the dams. From Lock No. 4 to Wetumpka, Ala., a distance of 116 miles, there occurs a succession of rapids having a combined fall of 323 ft. In this section no work of improvement has been done, except at Wetumpka, where the

* Presented at the meeting of May 20th, 1903.

masonry of Lock No. 31 has been finished and a lock-master's house built. From Wetumpka to the mouth of the Coosa, a distance of 14 miles, the fall is gentle, and no locks and dams will be required. From Wetumpka to Mobile, Ala., a distance of 377 miles, there has always existed navigation for light-draft boats the year round.

It will thus be seen that on this system of rivers there would be, with the improvement of the 116 miles now closed to navigation, a water route of transportation from the mountains of Georgia to the Gulf, at Mobile, a distance of 786 miles.

The Coosa and Alabama Rivers were discovered by DeSoto in 1540. He marched down the entire length of the Coosa, and down the Alabama to the Choctaw Bluff, where, in an engagement with the tribe of Mobile Indians, his force was greatly weakened, though he almost annihilated the tribe of Indians.

After DeSoto's glimpse of them, these rivers almost disappeared from the knowledge of civilized man for nearly a century and a half. The words of Mark Twain, referring to the discovery of the Mississippi by the same explorer, apply equally well to the Coosa and Alabama Rivers:

"Apparently nobody happened to want such a river; nobody needed it, nobody was curious about it; so, for a century and a half, the Mississippi remained out of the market and undisturbed. When DeSoto found it, he was not hunting for a river, and had no present occasion for one, consequently, he did not value it or even take any particular notice of it."

Geologically, the Coosa flows through the formations of the Paleozoic Era to within 27 miles of Wetumpka. Through this last part of its course it flows over crystalline rocks of pre-Cambrian origin, and at Wetumpka enters the coastal plain and the Cretaceous formation.

Through its upper course the river passes through the Coosa coal field near Lock No. 4, and, in places, the bluffs forming its banks contain great deposits of iron ore and limestone. In this section occur also deposits of bauxite, roofing slates, and great forests of long-leaf (Southern) pine and hardwoods of many varieties.

The drainage area of the Coosa Basin, to Riverside, Ala., 113 miles above Wetumpka, including its tributaries, is given by the Hydrographic Division of the United States Geological Survey at 6 850 sq. miles.

The country adjacent to the Alabama River, while rich, agriculturally, has few, if any, mineral resources.

The banks of the Coosa, over the 116 miles to be improved, are generally high, and in many places they are precipitous, rocky bluffs. On such a stream, then, high lifts for locks and dams could be used without submerging much of the adjoining lands.

The questions now arise: First, what is the economic depth? and, second, what is the economic lift? Upon the correct answers to these two questions depends the proper solution of the problem, and in answering them the effort will be made to reduce the problem to the economic basis of business principles; the principles that govern the location of railroads, and the inauguration and construction of other works of a public character.

Two depths for the navigation of these rivers have been proposed, namely, 4 ft. and 6 ft. The present discussion, therefore, will be confined to these two depths, for to extend it to others would carry the paper far beyond the limits proposed.

Acting under the direction of Captain R. R. Raymond, Corps of Engineers, U. S. A., the writer has deduced two equations, showing the relations between lift and cost of locks and accessories of standard design for the Coosa River, one for 4-ft. and one for 6-ft. navigation. The equations, the method of their deduction, and the theoretic economic effect of the use of the economic lifts are given in what follows, together with a discussion of other economic questions relating to the improvement.

Assuming the river to have a uniform slope and cross-section, the cost of one lock can be stated as follows:

Y = cost of one lock and accessories, in terms of the lift, = C + cost of excavation + cost of lock-walls + cost of wing-walls + cost of gates + cost of valves + cost of dam + cost of abutment + cost of guide piers + cost of engineering, inspection and office expenses.

The constant, C, includes:

Gate-maneuvering machinery	$410
Coffer-dam	5 000
Lock-house	3 000
Fencing and outbuildings	1 500
Lock site	1 000
Miter-sills	1 206
	$12 116

The expressions for the variable costs entering the equation, in which x, the lift, is a factor, are as follows:

Cost of excavation =

$$\left(\frac{x+m+d+e+w}{10}\right) l\, e$$

Cost of walls =

$$\tfrac{7}{2\,7}\left[\left(k+\frac{m+x+d+e}{2}\right)\left(\frac{m+x+d+e}{2}\right) 2\,l + \left(\frac{m+x+d+e}{2}-k\right)(m+x+d+e)\,l''\right]$$

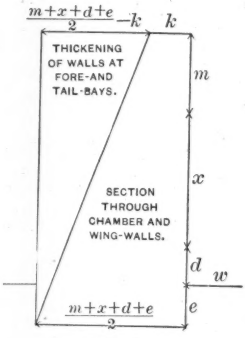


FIG. 1.

Cost of wing-walls =

$$\tfrac{7}{2\,7}\left(k+\frac{m+x+d+e}{2}\right)\left(\frac{m+x+d+e}{2}\right) l'''$$

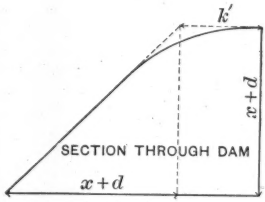


FIG. 2.

Cost of gates =

$$4\, s\, (m+x+d)\sqrt{\tfrac{5}{1\,6}\, w^2}$$

Cost of valves $= s'\left(\frac{4\, A\sqrt{x}}{+c\sqrt{2\, g}}\right)$

Cost of dam =

$$\tfrac{1}{9}\, l'\left[(2\, k'+x+d)\left(\frac{x+d}{2}\right)\right]$$

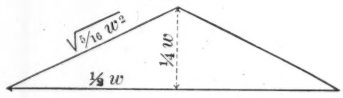


FIG. 3.

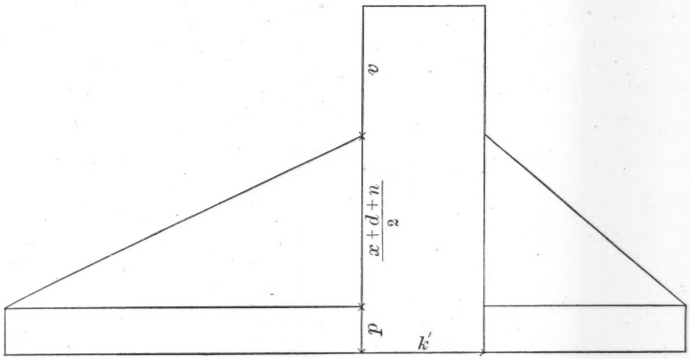
Cost of abutment $= \tfrac{8}{2\,7}\left[p\,(2\,x+2\,d+2\,k'+n)\left(\frac{x+d+n}{2}\right) + \tfrac{1}{3}\left(\frac{x+d+n}{2}\right)^2\left(2\,x+2\,d+n\right)+\left(\frac{x+d+n}{2}+v\right)(x+d+n)\,k'\right]$

Cost of guide piers $= 300\, x$.

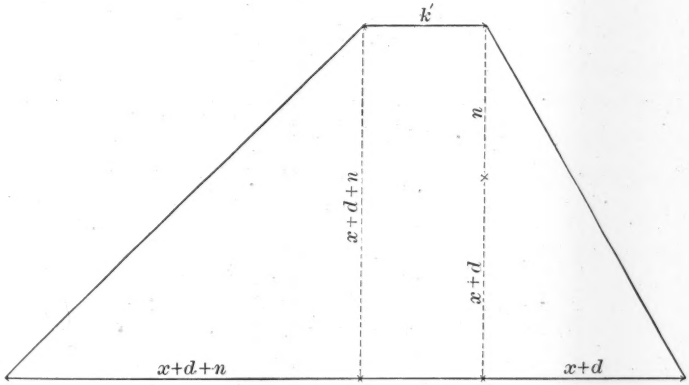
Cost of engineering, inspection, etc., $= 1\,500\, x$.

The values given the letters are the respective dimensions, etc., proposed for the locks, dams, etc., except the length of the dams, which is assumed. Unit prices are based upon the cost of similar work on this and the Warrior River.

SKETCH OF ABUTMENT.



PLAN.



FRONT ELEVATION.

FIG. 4.

l = length of lock, over all = 400 ft.;
m = guard of lock-walls = 8 ft.;
w = width of lock-chamber = 52 ft.;
k = width of lock and wing-wall coping = 4 ft.;
d = depth of water over miter-sills = 4 and 6 ft.;
s = cost per square foot of gate = \$3.81;
s' = cost per square foot of valve = \$15.59;
A = area of lock-chamber = 16 744 sq. ft.;
t = 360 seconds of time;
c = 0.635, determined from experiments at Lock No. 3, Coosa River;
k' = width of crest of dams = 8 ft.;
l' = average length of dams = 800 ft.;
p = width of abutment coping = 4 ft.;
n = guard of abutment = 14 ft.;
v = length of abutment stem = 10 ft.;
l'' = half length of heavy walls at fore- and tail-bays = 140 ft.;
l''' = length of wing-walls = 100 ft.;
e = depth of excavation = 4 ft.;
g = acceleration due to gravity = 32.2;

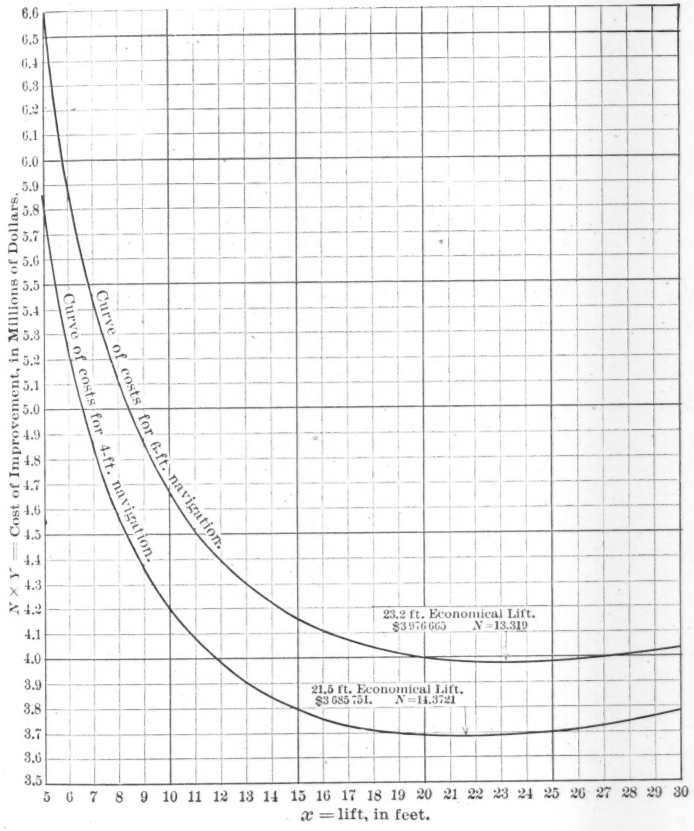
Substituting these values in the foregoing equations, and making $d = 4$, we get for 4-ft. navigation:

C = \$12 116.00;
Cost of excavation = \$10 880 + $160x$;
Cost of lock-walls = \$22 234.07 + 2 509.62x + 70x^2;
Cost of wing-walls = \$2 488.88 + 259.26x + 6.48x^2;
Cost of gates = \$5 316.32 + 443.03x;
Cost of valves = \$569.19$\sqrt{x}$;
Cost of dam = \$3 555.55 + 1 066.67x + 44.44x^2;
Cost of guide piers = \$300x;
Cost of engineering, inspection, etc., = \$1 500x;
Cost of abutment = \$1 403.85 + 145.78x + 4.69x^2 + 0.0494x^3.

And Y = \$57 994.67 + 569.19$\sqrt{x}$ + 6 384.36x + 125.61x^2 + 0.0494x^3 ..... (1)

Again, substituting in the equations the values of the letters, and making $d = 6$, we get, for 6-ft. navigation:

C = \$12 116.00:
Cost of excavation = \$11 200 + 160x;
Cost of lock-walls = \$27 533.33 + 2 789.63x + 70x^2;


6.6
6.5
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N × Y = Cost of Improvement, in Millions of Dollars.
Curve of costs for 6-ft. navigation.
Curve of costs for 4-ft. navigation.
23.2 ft. Economical Lift.
$3 976 665 N = 13.319
21.5 ft. Economical Lift.
$3 685 751. N = 14.3721
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
x = lift, in feet.

FIG. 5.

Cost of wing-walls $= \$3\,033.33 + 285.19x + 6.48x^2$;

Cost of gates $= \$6\,202.38 + 443.03x$;

Cost of valves $= \$569.19\sqrt{x}$;

Cost of dam $= \$5\,866.67 + 1\,244.44x + 44.44x^2$;

Cost of guide piers $= \$300x$;

Cost of engineering, inspection, etc., $= \$1\,500x$;

Cost of abutment $= \$1\,702.72 + 165.13x + 4.99x^2 + 0.9494x^3$,

And $Y = \$67\,654.43 + 569.19\sqrt{x} + 6\,887.42x + 125.91x^2 + 0.0494x^3$. . . . . (2)

The fall from the lower pool at Lock No. 4 to the upper pool at Lock No. 31 is 309 ft. Let the number of locks required, with any lift, x, to overcome this fall $= N$; then $N = \frac{309}{x}$, and the cost of the improvement, exclusive of levees and overflowed lands, the cost of which is at present unknown, is $Y \times N$.

Tables Nos. 1 and 2 give the values of Y and N, and the total cost of the improvement, for every value of x, increasing by increments of 1 ft. from 5 to 30 ft., inclusive, for both 4-ft. and 6-ft. navigation. The curves in Fig. 5 show graphically the costs given in the tables.

TABLE No. 1.—VALUES OF Y AND N, AND TOTAL COST OF THE IMPROVEMENT FOR EVERY VALUE OF x, INCREASING BY INCREMENTS OF 1 FOOT FROM 5 TO 30 FEET.

FOR 4-FOOT NAVIGATION.

x, in feet.	Y.	N.	$Y \times N$. Costs of system.	
5	$94 334.38	61.8	$5 829 865	
6	102 227.70	51.5	5 264 727	
7	110 362.94	44.1	4 867 006	
8	118 743.81	38.6	4 583 512	
9	127 371.89	34.3	4 368 786	
10	136 247.31	30.9	4 210 042	
11	145 375.02	28.1	4 085 038	
12	154 751.92	25.75	3 984 802	
13	164 380.24	23.77	3 907 318	
14	174 260.53	22.07	3 845 930	
15	184 393.53	20.6	3 798 507	
16	194 779.70	19.31	3 761 196	
17	205 419.54	18.17	3 732 473	
18	216 313.78	17.17	3 714 108	
19	227 462.59	16.27	3 700 816	
20	238 866.56	15.45	3 690 488	
21	250 526.10	14.7143	3 686 316	21.5 ft. economical lift.
22	262 441.59	14.05	3 687 304	$3 685 751. $N = 14.3721$.
23	274 613.44	13.435	3 689 432	
24	287 042.01	12.87	3 694 233	
25	299 727.74	12.36	3 704 635	
26	312 670.92	11.88	3 714 531	
27	325 872.05	11.44	3 727 976	
28	339 331.34	11.04	3 746 218	
29	353 049.16	10.65	3 759 974	
30	367 025.89	10.30	3 780 867	

TABLE No. 2.—VALUES OF Y AND N, AND TOTAL COST OF THE IMPROVEMENT FOR EVERY VALUE OF x, INCREASING BY INCREMENTS OF 1 FOOT FROM 5 TO 30 FEET.

FOR 6-FOOT NAVIGATION.

x, in feet.	Y.	N.	$Y \times N$. Costs of system.	
5	$106 518.21	61.8	$6 582 825	
6	114 916.61	51.5	5 918 205	
7	123 558.84	44.1	5 448 945	
8	132 447.24	38.6	5 112 463	
9	141 583.51	34.3	4 856 314	
10	150 972.11	30.9	4 665 048	
11	160 604.71	28.1	4 512 992	
12	170 491.55	25.75	4 390 157	
13	180 630.51	23.77	4 293 587	
14	191 021.95	22.07	4 215 853	
15	201 666.68	20.6	4 154 334	
16	212 565.26	19.31	4 104 635	
17	223 718.11	18.17	4 064 958	
18	235 125.82	17.17	4 037 110	
19	246 788.80	16.27	4 015 254	
20	258 707.53	15.45	3 997 031	
21	270 882.41	14.71	3 984 680	
22	283 313.87	14.05	3 980 560	
23	296 002.25	13.4348	3 976 731	23.2 ft., economical lift.
24	308 947.99	12.875	3 977 705	$3 976 665, $N = 13.319$.
25	322 151.53	12.36	3 981 793	
26	335 613.05	11.88	3 987 083	
27	349 333.21	11.44	3 996 372	
28	363 311.90	11.04	4 010 963	
29	377 549.94	10.65	4 020 907	
30	392 047.44	10.30	4 038 089	

The present project for the improvement of the Coosa River contemplates the building of twenty-seven locks and dams, from Lock No. 5 to Lock No. 31, inclusive. Lock and lock-house No. 31 have been completed, but the dam, gates, valves, etc., are yet to be built.

Table No. 3 gives the estimated cost of the improvement under the present project; the cost by Equations 1 and 2 for the lifts proposed in the present project, and the minimum costs by Equations 1 and 2, using the economical lifts. It will be noticed that the locks and dams provided for in the approved project, from Nos. 5 to 30, inclusive, have a combined lift of 296 ft., leaving 13 ft. fall in parts of the river where the slope is gentle. It is in these parts that $407 201 would be expended for channel work. In the estimates by Equations 1 and 2 it is proposed to back the water from one lock to another, and locate all locks so that channel work would be eliminated. The difference in cost of the locks of the present project and the costs given by Equations 1 and 2 for the same lifts is due to the substitution of concrete for cut-stone masonry in the latter, thereby reducing greatly their cost. The lock masonry and lock-house for No. 31, being finished, are omitted from the estimates of costs in Table No. 3.

TABLE No. 3.

Number of locks.	Lift, in feet.	Cost (estimated) of present project.	Cost (estimated) by Equation 1.	Cost (estimated) by Equation 2.
4	8	$654 952	$474 975	$529 789
10	10	1 756 670	1 362 473	1 509 721
7	12	1 304 590	1 083 263	1 193 441
1	13	191 734	164 380	180 631
3	14	596 502	522 782	573 066
1	15	204 673	184 393	201 667
Total cost of present project.		$4 709 121		
Dams, abutments, houses, etc.		757 257		
Dams, guide piers, valves, gates, machinery, inspection, Lock No. 31.		11 302*	56 476*	63 270*
Total costs.		$5 477 680	$3 848 742	$4 251 585
Minimum costs by Equations 1 and 2, with economical lifts.			3 685 751	3 975 665

* Gates, valves and maneuvering machinery of Lock No. 31.

The minimum costs given by Equations 1 and 2 must be increased by the cost of the dam, guide piers, etc., at Lock No. 31, $56 476 and $63 270, respectively. These minimum costs will then be:

For 4-ft. navigation $3 742 227;
For 6-ft. navigation..... 4 039 935.

The substitution of the economical lifts, 21.5 ft. and 23.2 ft. for 4-ft. and 6-ft. navigation, respectively, and the substitution of concrete for cut-stone masonry, would result in a saving:

For 4-ft. navigation..... $1 735 453;
For 6-ft. navigation..... 1 437 745.

But the present project includes $407 201 for channel work, which is eliminated from the proposed economical project; therefore, the total saving would be:

For 4-ft. navigation..... $2 142 654;
For 6-ft. navigation..... 1 844 946.

Comparing the costs given by Equations 1 and 2, using the lifts of the present project, with the costs given by those equations using the economical lifts, we find that there is a saving from the use of the economical lifts:

For 4-ft. navigation..... $106 515;
For 6-ft. navigation..... 211 650.

Assuming that a lockage requires 20 minutes, there would result a saving in time over the time required for lockages under the present project:

For 4-ft. navigation (26 — 15) 20 = 3 hours 40 minutes;
For 6-ft. navigation (26 — 14) 20 = 4 hours.

The average cost of operating Locks Nos. 1, 2 and 3 on the Coosa River, for ten years past, has been for each lock:

For lock-master's wages	$600
For maintenance	1 000
Total	$1 600

The saving on this item would be:

For 4-ft. navigation (26 — 15) 1 600 = $17 600;
For 6-ft. navigation (26 — 14) 1 600 = 19 200.

Capitalizing these sums at 3%, there would result from this reduction of locks the equivalent of a permanent investment:

For 4-ft. navigation $586 667;
For 6-ft. navigation ..... 640 000.

The Government, therefore, could spend for overflowed lands the sums saved by the adoption of the economical lift, even though the saving to the public in reduced freight rates, due to decreased lockages, were not considered. These sums are as follows:

For 4-ft. navigation, 106 515 + 407 201 + 586 667.= $1 100 383;
For 6-ft. navigation, 211 650 + 407 201 + 640 000 = 1 258 851.

The uneconomical character of the present project is so apparent, from what has gone before, that in the further discussion of the subject it will not be considered. It should be stated, however, that the present project is designed to have 6 ft. of water over the miter-sills of the locks and 4 ft. in the river channel.

Water Powers.—It has not been the policy of the Government, heretofore, to utilize for commercial purposes the power developed at dams built for purposes of navigation; but the increasing use of electrical transmission of power, and the facility with which such transmission can be operated over long distances to places where the power can be used economically, will probably necessitate an early change in this policy. In view of these changed conditions, it will be well to

consider here the effect which a judicious use of the power developed at the dams on this river would have upon the improvement from an economic point of view.

The low-water discharge of the Coosa River has been estimated variously at from 1 500 to 5 000 cu. ft. per second. Assuming the discharge at 2 000 cu. ft. per second, there could be developed at each dam:

With dams for 4-ft. navigation (21.5 ft.).... 4 887 H.-P.
With dams for 6-ft. navigation (23.2 ft.).... 5 273 H.-P.

Allowing 50% for losses and the maintenance of navigation, there would remain for commercial purposes:

With dams for 4-ft. navigation..... 2 443 H.-P.
With dams for 6-ft. navigation..... 2 636 H.-P.

Assuming that the fall at the dams will disappear when the river below each dam rises to twice its height, which is approximately true, then, to overcome all fall at the dams, it would require:

With dams for 4-ft. navigation, a rise of 43 ft.
With dams for 6-ft. navigation, a rise of 46.4 ft.

Such rises on that part of the Coosa River under consideration are unknown.

The average yearly maximum rise at Lock No. 4 is 20 ft. Such a rise would leave a head as follows:

On dams for 4-ft. navigation, 11.5 ft.
On dams for 6-ft. navigation, 13.2 ft.

By providing additional water-wheels, the low-water power at each dam could be maintained.

The rentals of water-powers in the United States range from $5 to $45 per horse-power per year. Neglecting the fractional dams, and assuming that the Government leased or rented the power at all the others for the reasonable sum of $5 per horse-power per year, the income from this source would amount to:

From dams for 4-ft. navigation..... $171 010;
From dams for 6-ft. navigation..... 171 340.

Capitalized at 3%, these sums would pay interest:

From rental of power at dams for 4-ft. navigation, on $5 700 333;
From rental of power at dams for 6-ft. navigation, on $5 711 333.

In other words, the Government could, from this source, pay interest on the improvement; pay operating and maintenance expenses; and have remaining a sum sufficient to pay interest:

With 4-ft. navigation, on

$$\$5\ 700\ 333 - \left(3\ 742\ 227 + \frac{24\ 000}{0.03}\right) = \$1\ 158\ 106;$$

With 6-ft. navigation, on

$$\$5\ 711\ 333 - \left(4\ 039\ 935 + \frac{22\ 400}{0.03}\right) = \$924\ 731.$$

These sums could be used in the erection of power plants at the dams or for other purposes.

It is not probable that the Government could rent the power at all the dams; but it is reasonable to assume that enough could be rented to pay operating and maintenance expenses and interest on the cost of the improvement.

The Alabama River.—The distance from Wetumpka to the mouth of the Coosa is about 14 miles; but as this part of the river is of the same character as the Alabama, for the purposes of this paper, it will be treated as part of that river.

The distance from Wetumpka to the mouth of the Alabama is 332.5 miles; the fall is 105 ft.

The banks of the Alabama are low, and the bottom lands on either side extend back 5 to 10 miles from the river. Like the Mississippi, the Alabama has banks that are caving constantly, and a bottom ever on the move; and unless movable dams were used, the pools would soon fill, leaving the river in worse condition than now, for constant dredging between locks would be necessary to maintain a channel. If dredging will have to be resorted to finally, then the construction of locks and dams, leaving out of consideration the danger to adjoining lowlands, would be more than a useless expense, and, therefore, the problem of improving this river resolves itself into a question of maintaining a low-water channel of the required depth by means of dredging.

The question of works of contraction is not considered, for experience on this and other rivers of the same character has been that such works merely move the obstructions, which they are intended to overcome, further down stream, and, that, to make such works effective, they would have to be built in such manner and places as to

give the river, as a whole, a uniform slope and cross-section. The cost and maintenance of such a system would be prohibitive.

Unfortunately, no data exist upon which an accurate estimate of the improvement of the Alabama River can be based; but the writer believes, from his personal knowledge of this stream, that the estimates for dredging that follow are sufficient to maintain the channels proposed.

The following is an estimate of the annual cost of operation of one dredging plant:

One dipper dredge of 1½ cu. yds. dipper capacity	$15 000
Three dump scows	9 000
One steam tender	15 000
Total	$39 000
Assuming renewals every 15 years:	
Cost per year for plant	$2 600
Repairs	300
Crew of dredge, 6 months	1 710
Subsistence, 6 months	600
Fuel for dredge, 6 months	500
Oil, waste, etc., 6 months	130
Tender crew, 6 months	1 830
Fuel for tender, 6 months	500
Subsistence, 6 months	600
Repairs, 6 months	200
Oil, waste, etc., 6 months	130
Two watchmen, 6 months	360
Contingencies, 10%	960
Total	$10 420

Assuming that six such dredging plants would maintain a 4-ft. channel and eight plants a 6-ft. channel, the cost per year would be:

For 4-ft. navigation $62 520;
For 6-ft. navigation ..... 83 360.

Capitalized at 3%, these sums would be interest charges on permanent investments:

For 4-ft. navigation $2 084 000;
For 6 ft. navigation ..... 2 778 667.

The total economical cost for the improvement of this system of rivers would therefore be:

For 4-ft. navigation:

Improving the Coosa River	$3 742 227
Improving the Alabama River, annual cost capitalized at 3%	2 084 000
Operation and maintenance of locks, Coosa River, capitalized at 3%	800 000
Total	$6 626 227
Deduct rental of power, capitalized at 3%	5 700 333
Cost to the United States	$925 894

For 6-ft. navigation:

Improving the Coosa River	$4 039 935
Improving the Alabama River, annual cost capitalized at 3%	2 778 667
Operation and maintenance of locks, Coosa River, capitalized at 3%	746 667
Total	$7 565 269
Deduct rental of power, capitalized at 3%	5 711 333
Cost to the United States	$1 853 936

A little more than twice the cost of the improvement for 4-ft. navigation.

But there is another factor entering into the problem: The freight rate. As coal will probably be the principal freight carried on this system of rivers, it is taken as the basis of comparison. The locks, as designed, will take at one lockage three barges and one towboat. This fleet is the basis of the following estimate:

	For 4-ft. channel.	For 6-ft. channel.
Cost of steamboat per year	$667.67	$800.00
Cost of barges "	500.00	600.00
Repairs "	300.00	325.00
Interest on first cost at 4% "	700.00	840.00
Insurance at $\frac{5}{8}$ of 1% "	75.00	93.75
Taxes "	187.50	225.00
Two Masters "	1 680.00	1 680.00
Two Engineers "	1 200.00	1 200.00
Two Firemen "	960.00	960.00
Six Men "	2 160 00	2 160.00
Subsistence "	1 200.00	1 200.00
Fuel "	1 000.00	1 200.00
Supplies "	200 00	200.00
	$10 830.17	$11 483.75

Cost per trip, thirty trips per year	$361.00	$382.79
Capacity of fleet	848 tons	1396 tons
Cost per ton of freight	$0.426	$0.274

Now, the value of any improvement is inversely as the first cost, the capitalized cost of operation and maintenance, the cost per ton freight rate; and directly as the capitalized investment resulting from the rental of power developed at the dams. Applying this rule to the present discussion, we have:

$$\text{For the value of 4-ft. navigation } \frac{5\,700\,333}{3\,742\,227 + 2\,084\,000 \times 800\,000 \times 0.426}$$

$$\text{For the value of 6-ft. navigation } \frac{5\,711\,333}{4\,039\,935 + 2\,778\,667 \times 746\,667 \times 0.274}$$

Dividing the second equation by the first, we find that the value of 4-ft. navigation is to the value of 6-ft. navigation as 1 to 1.4621.

The tendency, in the United States, is to increase the navigable depth in rivers under improvement. Upon the system of rivers under discussion, at least, this is good practice, both from the point of view of the carrier and as an economic proposition. There is, unquestionably, an economic depth, just as there is an economic lift, but this paper cannot go further into a discussion of that phase of the problem.

In the final location of the locks on the Coosa River, it will be impossible, of course, to adhere to the economic lift indicated, but it will be possible to approach it, and the nearer the approach the more economical the improvement.

The writer has had access to excellent maps and profiles of the part of the Coosa River under consideration. The maps, however, do not show the topography of the adjacent country, and, therefore, it has been impossible to estimate the cost for levees and overflowed lands; but, as before stated in this paper, the banks are high, and in many places precipitous, and these costs would be comparatively small. This part of the Coosa is an ideal stream for locks and dams of high lift.

The writer knows of no good map of the Alabama River, and, as far as his knowledge goes, there is no profile in existence. The estimates for that river are made from his personal knowledge of the stream, and are believed to be safe.

The writer's investigations have led him to the following general conclusions concerning the improvement of rivers in the United States:

All streams, east of the Mississippi at least, and generally those west of that river, may be classified under two heads, which, for want of better names, will be called torrential and alluvial.

Torrential streams are those pouring down from the mountains and plateaus, and emptying generally into alluvial streams. They can only be opened to navigation by means of locks and dams.

Alluvial streams are those flowing through the coastal plain, and are always continuations of torrential streams. Except when the flow is insufficient to maintain the required navigable depth, alluvial streams should never be improved by means of locks and dams, for, with their caving banks and moving bottoms, the pools would soon fill, and constant dredging would be required to keep them open to navigation. Movable dams would remove this objection, but, with the present navigation on our rivers, their cost is prohibitive.

The use of isolated works of contraction on alluvial streams is a mere expedient, for their only effect is to move the obstruction further down stream. Of course, other contraction works could be built, until the obstruction was removed to the mouth of the river. Such extensive works of regulation would result in giving the stream a uniform slope and cross-section, and are an excellent method of improvement, except as to the cost, which would be enormous.

Finally, there is left the method of maintaining a temporary channel, during periods of low water, by dredging. This is the cheapest, and, with the present traffic on our rivers, is the one that should be used.

Our larger problems of river improvement embrace the study of the regulation of both torrential and alluvial streams in one and the same project. Every such system should be treated as a whole. It is as bad practice to have one part of a system improved for one depth of navigation and another for a different depth as it would be to have different gauges in the same system of railroads.

The time has come when the power developed by dams built for purposes of navigation should be used in the industrial development of the country. This being true, why should not the public at large, as represented by the Government, reap some of the benefits?

DISCUSSION.

Capt. Raymond.

CAPT. R. R. RAYMOND* (by letter).—It will be remembered that the Coosa River improvement was vigorously attacked and defended in Congress during the debates on the last River and Harbor bill. The work on the improvement had been practically abandoned a few years ago, and the many valid and wise arguments against further expenditure, considered together with the flowery eloquence invoked in its defence (a sure sign of a weak case), apparently promised a complete abandonment of the river as a navigable waterway. All that could be gained by the advocates of an appropriation was a provision, in the Act of June 13th, that a new survey should be made with funds remaining from former appropriations, amounting to about $13 000.

It became the writer's duty to devise a project for making this survey, and at first it seemed almost a waste of money to obtain more data when the information already available was ample to show the uselessness of completing the improvement.

Since no further survey was needed for the discussion of the existing project, it was natural to examine the project itself to determine what improvement therein was possible, and what information would be required to devise a new and improved project.

As a project to obtain 6-ft. navigation at a minimum cost was desired, a formula became necessary, from which, by means of the ordinary methods of the calculus, the proper mean lift could be determined. Mr. Andrews has deduced this formula, as explained by him, and the possibility of making changes in the existing project which might make the improvement of the river profitable was clearly shown.

It should be noted that Mr. Andrews has not attempted to deduce a new scheme of improvement or regulation of the stream. He has simply shown, by a discussion of ideal conditions, assumed to agree as nearly as possible with what may be termed mean actual conditions, that there is for this river some scheme of regulation which will give the best results for the least outlay.

His study of the problem, having pointed out the additional information needed to prepare the new project, has fulfilled its purpose.

The new survey will probably be made within the year, and it will then be possible to study actual as well as ideal conditions, and decide upon a plan which will give not only the greatest economy, but also provide the most suitable depth of channel.

One very important feature of the paper is its reference to the utilization of the water-power. This is the greatest water-power in

* Corps of Engineers, U. S. A.

the South. Not one horse-power is now saved. A few applications have been made to Congress for authority to erect power plants on this stream. Such applications have been recommended for approval by the Engineer Officer in charge of the river, but none has as yet been successful in Congress. There is no mechanical or moral objection to the development of this great source of wealth for the South; and it is to be hoped that it will not be defeated for political reasons. Capt. Raymond.

D. M. ANDREWS, M. Am. Soc. C. E. (by letter).—The writer regrets that there was no discussion of his paper, other than the very interesting letter from Captain Raymond, for, as far as his knowledge goes, the study of the theoretic economic factors entering the problem of the improvement of rivers in the United States is new, though the late A. M. Wellington, M. Am. Soc. C. E., had "pointed the way" in his "Economic Theory of the Location of Railways." Mr. Andrews.

While the writer's paper was confined to the narrow limits of a discussion of the Coosa and Alabama Rivers, the subject is susceptible of wide application and great amplification. As a single example of this, it can be shown that the value of lowlands adjacent to the Coosa River is small compared to the value of those adjoining torrential streams in, say, the States of New York and Ohio. In applying the study to such streams in those States, the question of overflowed lands would enter as a much more important factor than in Alabama, and the economic lift would thereby be very greatly affected.

It is hardly necessary to say that the determination of the theoretic economic lift, and depth of channel, for every system of unimproved or partly improved rivers, is well worth the while.

The importance of the conservation of the water-powers on our streams cannot be too strongly emphasized, and, therefore, in the adoption of any scheme for the improvement of our rivers by means of locks and dams, the lifts should be made as high as is consistent with true economy.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 953.

A NEW SAFETY EXPLOSIVE.*

By Richard T. Dana, Assoc. M. Am. Soc. C. E.

With Discussion by A. McC. Parker, M. Am. Soc. C. E.

Since the days of Nobel's invention of dynamite, his mixture, or a close approximation to it, has been used in practically all industrial work requiring the use of a high explosive—until very recent years.

For some ten or fifteen years in Europe, and two or three years in this country, there have been coming into use some explosive compounds of the nitro-substitution class, so-called, which are claimed to have advantages over the dynamites, from the standpoints of non-freezability, safety in handling, and certain other points, varying with the particular compound.

In the summer of 1900, while on the New York Division of the Erie Railroad, the writer had occasion to recommend for trial an explosive having picric acid and sodium nitrate for the principal constituents, and which was advertised to be rather higher in power than 40% dynamite. There had recently been an explosion of dynamite in storage, for which no definite cause was discovered, and which was rather expensive; moreover, the 40% dynamite was thought to be a little weak for the rock to be handled, which was a hard metamorphic rock, called by the natives "bastard trap."

* Presented at the meeting of June 3d, 1903.

A box of this material, known as Joveite, was ordered, and careful tests made under the supervision of the writer, the results of which, with some supplementary tests which he made later, were as follows:

The material is a yellow powder, resembling corn meal, put up in cartridges similar to those of dynamite in size and shape. A quantity of the powder was placed on a rail and hammered with a sledge without result until after several trials a spark was struck, and the powder remaining on the rail burned up with about the rapidity of celluloid.

A stick was then fired into with a shot-gun without result, and then small quantities of equal bulk of Joveite and 40% dynamite were detonated on the corners of a wrought-iron plate, with a view to determine the intensity of explosion. The indication from two trials was that dynamite was a little the quicker. Several trials were made by mudcapping, in comparison with 40% dynamite, and no difference in the results detected. The powder was then used in the rock itself, and gave results practically identical, as far as work was concerned, with those from dynamite. Its general use was then recommended, and has been continued up to the present.

Joveite is somewhat lighter, bulk for bulk, than dynamite, the proportion being 2 to 3, and it was found that it would do just about the same amount of execution in the rock, bulk for bulk. This made the cost the same, or a little less, the price per pound being 11 or 12 cents. The material is a dry powder and therefore will not freeze. It has been used in the coldest weather without noticeable variation in strength or sensitiveness, and, as far as the writer knows, has never exploded accidentally.

As soon as the men became familiar with the material they began to take liberties with it, such as tamping it heavily in the hole. This gave rise to trouble, in the first few months of its use, for the cartridge in which it was put up was made of paper and frequently burst under this treatment, with the result that the powder was not properly confined in the hole and there were a number of cases of imperfect detonation. The powder is not easily detonated when wet, and, loaded in wet holes, its use was very unsatisfactory, dynamite being substituted; but, recently, the manufacturers have devised a water-tight cartridge with a cloth fiber, which admits of considerable tamping and distortion without becoming pervious. Loaded in this manner, its use is eminently satisfactory.

The men in the quarry had complained of the well-known effect of the nitro-glycerine fumes from dynamite. The writer made a careful examination of Joveite, in this particular, and did not succeed it getting a suspicion of headache from it, and he has heard no complaints in this respect, with one exception, which was at second-hand, and which he was unable to verify. When detonated, it has a distinctly perceptible odor, which is slightly suggestive of nitro-glycerine, but is not unpleasant.

The detonation is accomplished in the ordinary manner, by the use of a single-strength fulminate-of-mercury cap, either with a powder fuse or fired from a battery. In firing with a fuse, some trouble was experienced occasionally, from the fact that the material is inflammable. When the cap was inserted too far into the cartridge, the fire from the fuse itself would sometimes be communicated to the powder before the primer was fired, which resulted in a "flower pot." This was obviated by the use of electric fuses, or, on the other hand, by a little care in the setting of the powder fuse. It is to be regretted that in many cases owners of quarries still use the old Bickford type of fuse.

In the spring following the disastrous dynamite explosion at Forty-second Street, in New York City, the manufacturers of Joveite held a public exhibition of their product, at which they ignited a pile of boxes containing 600 lbs. of the explosive. The exhibitors said that their only feeling of nervousness was lest by some faint chance a mercury primer might have got among the boxes. The crowd stood about 80 yds. from the boxes, and it must be confessed that while the mass was taking fire the situation was decidedly interesting. About 150 or 200 lbs. of the explosive burned up immediately, scorching and charring the remaining boxes, which had not been broken open. These were then broken open and lighted, when the mass blazed up and was entirely consumed, with the evolution of a dense white smoke, and no very noticeable odor. Another interesting demonstration* was that of dropping a 200-lb. weight upon a box of the explosive in which were scattered bits of iron, nails, etc., resting on an anvil. The fall was about 30 ft., producing sufficient heat of friction and impact to ignite the powder.

A very important point, which the writer does not think has yet

* Mentioned in a letter by the writer, in *Engineering News*, January 22d, 1903.

been established definitely, is whether this explosive can be made to detonate without flame. It is claimed, by the manufacturers of a rival powder, that their product is absolutely flameless, and can be used safely in mine workings where there is a large quantity of dust, fire-damp, etc., in the air. The manufacturers of Joveite say that, under special conditions, where a perfect detonation can be effected, they think that there is no flame from their product. In a mine, under service conditions, they do not claim entire immunity from flame. It has not yet been demonstrated, to the writer's satisfaction, that any explosion accompanied by evolution of heat is not, under some conditions, likely to be also accompanied by flame. Moreover, the question is still open whether fire-damp or mine dust, with a proper admixture of gases, may not be detonated by shock. In the writer's opinion, the most instructive experiments with Joveite were witnessed by him at the company's laboratory in March, 1903.

Two sticks of the material were placed on the ground, end to end, the adjacent ends being about 3 ins. apart, and one stick only detonated. Afterward, the other stick was detonated by itself. Two sticks were placed side by side, 4 ins. apart, and one detonated without detonating the other. A stick was placed on the ground, and a mercury fulminate cap of single strength was fired ½ in. from and pointed at the center of the stick. The blast from the cap tore open the cartridge and threw out some of the powder without detonating it.

A quantity of the powder was sprinkled upon a red-hot iron plate. As the particles touched the plate they flashed into flame with a sputtering, or burned quietly until consumed.

A small quantity of the powder was placed in a small glass tube which was in turn inserted into the middle of another tube and placed between the poles of an extremely powerful spark machine. The machine was easily capable of generating a continuous spark 14 ins. long, and was so powerful that it could not be operated for more than a few seconds at a time without burning out the heavy rubber insulation from the copper wires. When the spark was generated, it perforated the smaller glass tube, about 1½ ins. in length, longitudinally. The effect of the spark on the explosive was to fuse it and burst the tube. Most of the Joveite was burned, and none of it detonated.

A description of the process of manufacture of Joveite, kindly fur-

nished by Mr. Frank P. Harris, Chemist of the company, is as follows:

The powder is composed of a mixture of nitro-naphthalenes, nitro-phenols, and a metallic nitrate.

The proportions are as follows:

	No. 1.	No. 2.	No. 3.
Nitro-naphthalenes	9	10	8
Nitro-phenols	14	24	30
Metallic nitrate	77	66	62

Picric acid is used for the nitro-phenol, and is what gives the powder its yellow color. It should be noted, in passing, that this substance stains the hands of the workmen using it. The stains are almost impossible to avoid in using, unless the whole sticks, paraffined, are used, and the stains are exceedingly difficult to remove with the ordinary materials at the workman's command. The yellow stains are not easily visible by artificial light. Picric acid is soluble in alcohol and ether.

The metallic nitrate is dried thoroughly by means of a rotating-drum dryer, screened, and conveyed to a steam-heated room to be kept from absorbing moisture.

The nitro-napthalenes are first melted in a steam-jacketed kettle, and stirred by paddle arms, at the temperature of boiling water. Then the nitro-phenols are put in and melted, and, finally, the metallic nitrate, in the form of a dry powder, is stirred thoroughly with the other ingredients. After a time allowed for thorough mixing, the powder is removed to mechanical screens and there granulated to a free-running powder.

By using the nitro-napthalenes in this way it is possible to melt the nitro-phenols at a safe temperature, while the presence of nitro-naphthalenes in the finished product renders it quite insensitive to shock. By coating the grains of the metallic nitrates with the mixture of the nitro ingredients, the nitrates become protected from the atmosphere as by a varnish, for, while the nitro-phenols are slightly soluble in water, they are not deliquescent.

The quality of the powder depends wholly on the purity of the ingredients and the intimacy with which they are mixed.

The granulated powder is then packed in shells of various lengths and diameters, made of strong cloth-lined paper, and dipped in a paraffine solution, which renders them water- and moisture proof.

The finished shells are packed in wooden boxes, with no precaution as to jar or shock. The powder is also sold as a free-running powder, put up in water-proof bags.

"Spontaneous combustion is not possible. There is no instance known of a nitro-substitution compound, such as these, undergoing spontaneous decomposition; though the first of these bodies was discovered in 1788, and they have since been largely used in the arts."

Picric acid is $C_6 H_2 (N O_2)_3 O H$,
Sodium nitrate is $Na N O_3$,
Nitro-naphthalene is $C_{10} H_7 N O_2$.

The action of this material, taken together with its insensitiveness, would seem to indicate that it detonates rather more slowly than dynamite, and, if this may be said of any detonation, progressively.

The writer has considered this material in comparison with other high-power explosives in use, viewed in the light of the following considerations:

Any high explosive belongs to one of two general classes:

(1)—Explosives proper, which may be considered as represented by the "mixtures," such as gunpowder and the chlorate mixtures; and

(2)—Detonating "compounds," including the nitric derivatives, guncotton and nitro-glycerine, and the nitro-substitution compounds, such as Joveite, Masurite, Lyddite, Bellite, Securite, the Volney powders, Emmensite, Gelbite and Roburite. The line of demarkation between an explosion and a detonation is by no means absolutely defined in all cases, but, on the other hand, there are numbers of cases which are undoubtedly on one side or the other of this line. Black gunpowder, for example, when confined, is readily exploded by heat properly applied in the form of a spark. It is exceedingly difficult to detonate, however, without the admixture of a high explosive to give it sudden and great pressure. Iodide of nitrogen is readily detonated by a fly walking on it, but it is questionable whether it has actually been exploded progressively.

In the case of gunpowder, the explosion is the result of combustion instituted and propagated by a high temperature, in other words, heat. The cause of detonation is not quite so clear. Abel's theory of "Sympathetic Explosion" was that it was due to synchronous vibrations, the originating cause of the detonation being the synchronism between the vibrations produced by the body which provokes the

detonation and those which the first body would produce in detonating. Mr. Eissler, in his work on "The Modern High Explosives," states that:

"The propagation of explosions by influence is not made in virtue of an undulatory movement, which is a complex motion of a chemical and physical order in the midst of the explosive substance which is decomposed, while it is purely physical in the midst of intermediary substances which suffer no decomposition. But that which distinguishes this sort of movement of the vibrations, properly so called, is, first of all, the magnitude of the mechanical energy which it transmits; it is also the unique character of the explosive wave which is propagated in contra-distinction with the multiplicity of sonorous waves. Finally, it is essential to observe, that the explosive material does not detonate because it transmits the movement, but, on the contrary, because it arrests it, and because it transforms on the spot the mechanical energy into thermal energy, capable of suddenly raising the temperature of the substance up to the degree which will produce its decomposition."

A stick of Joveite, placed against an iron plate and fired upon with a steel-jacketed bullet from a high-powered rifle, will detonate. The impact of the bullet on the plate will generate considerable heat and at the same time set up a high order of vibration, neither of these agencies alone, as proved by the tests before mentioned, being adequate to produce that effect. The writer is informed that in the last-mentioned experiment a sheet of paper placed between the Joveite and the iron plate will nullify the effect.

The writer has concluded, then, that the statement made by the manufacturers of Joveite is correct, namely, that it requires for detonation a vibration of a certain quality and degree of intensity, together with a definite amount of heat.

The contrasted qualities of the safety explosives, as compared with dynamite, can most easily be considered by tabulating a number of the best-known characteristics of ordinary dynamite. These are as follows:

(1) Power;
(2) Cost; initial price;
(3) Rapidity of action;
(4) Facility and cost of detonation;
(5) Applicability to various conditions of work;
(6) Temperature of detonation;
(7) Freezing phenomena;
(8) Ease of transportation and cost;

(9) Ease of storage, and cost;
(10) Flame from explosion;
(11) Fumes, and effects from handling;
(12) Specific gravity;
(13) Risks; divided into: (*a*) risks from proper handling; and (*b*) risks from improper handling.

There is no satisfactory way of comparing the power of different explosives from the view-point of efficiency in the rock, except by actual tests under working conditions. The ordinary method for rough comparison is to load a mortar with a known weight of explosive, and observe the distance or height to which a projectile will be thrown. Another plan is to explode a small quantity of material within a lead casket, and note the deformation of the lead. Neither of these methods gives comparable results, for the reason that the observed effect depends upon three factors: The rapidity of detonation, the volume of gases generated, and the temperature of the gases found.

The rational criterion of the strength of any explosive is, of course, the amount of energy (*i. e.* force × distance) which a unit quantity will develop. Commercially, this is of little value, because of the well-known laws of blasting. In rather hard rock which is not very seamy the higher grade of Joveite, called *3xx*, is, from all the evidences which the writer could gather, more efficient than so-called 40% dynamite. It appears to have considerably more energy, pound for pound, but does not deliver such a quick, shattering blow as the higher dynamites. When used under conditions comparable to those for 40% dynamite it should be loaded in charges corresponding with normal dynamite charges, bulk for bulk, and will then give probably more economical results. For certain kinds of tunnel work in extremely hard and tenacious rock, or where the rock is much seamed and fissured, the higher grades of dynamite are probably more efficient than the *3xx* grade of Joveite as at present manufactured.

The foregoing remarks apply, of course, only to the grades of Joveite examined by the writer. It will be noted that the highest of these grades contains only 30% of picric acid. There is every reason to suppose that it will be practicable to make a grade of Joveite, containing, perhaps, more picric acid, very much more powerful than the present product, for fused picric acid is practically Lyddite, one of the most

powerful explosive substances known. Ecrasite, a salt of tri-nitro-cresol, in the same family as the picric salts, is said to be in effect twice as strong as dynamite. It is said that it is "made in Germany."

The cost of detonating Joveite is the same as that for dynamite, the same primer being used. A point which is not yet generally appreciated by workmen is that Joveite and dynamite, through improper setting, will not always detonate as they should, and, as a result, much labor and money are wasted. The point of setting the sticks in contact and, as nearly as possible, entirely filling the hole, with the maximum safe amount of tamping, is often lost sight of. In the tamping, Joveite has a great advantage, as it may be tamped heavily.

The range of practicable application for the "safety explosives" is large. The writer is informed that Joveite has been used successfully to break up frozen iron ore on the cars, an application probably quite beyond the reach of dynamite.

It may be transported long distances readily, and used for such purposes as digging post-holes in frozen ground. It should not be difficult to apply it to the driving of piles, the loosening of frozen earth and similar work.

The cost of transportation and storage of the safety explosives should be much less than with dynamite. In a railway collision, Joveite will presumably, at the most, burn up. In storage or transportation it is difficult to see where it is more dangerous than celluloid, except when adjacent to a box of fulminate caps.

The safety explosives may or may not be flameless, but the same thing is true of "carbo-dynamite" containing nitro-glycerine and charcoal.

The gases from the combustion of the picric acid compounds seem to be highly corrosive to iron and steel.

The following is a list of some of the dangers arising from the use of dynamite, which have been subdivided into two classes, and which, in the light of the facts outlined, point a striking moral:

(*a*) Dangers inevitable, even with reasonable care;

(1) Spontaneous explosion in storage;

(2) Lightning;

(3) Part of charge failing to go off and remaining undiscovered until exploded either by the sun's rays or by being struck by a tool;

(4) Train wreck;
(5) Drilling near missed hole;
(6) Flame. Fire-damp.

(*b*) Dangers incidental to the handling of dynamite as practiced every day;

(1) Dropping stick or box;
(2) Hole too small for cartridge; ramming down cartridge;
(3) Ramming too hard, or ramming with metal bar;
(4) Deepening missed hole;
(5) Returning to relight fuse;
(6) Testing the end of a hole with an iron bar after a blast, to see if any of the charge remains;
(7) Forcing primer into cartridge;
(8) Ramming in the first ball of tamping clay;
(9) Breaking a cartridge when near the freezing point;
(10) Stepping upon particles of explosive;
(11) Thawing in tin over a fire;
(12) Thawing in front of kitchen fire;
(13) Thawing in the men's boots or shirts;
(14) Thawing in an oven;
(15) Hot water containing dynamite placed on a blacksmith's fire;
(16) Thawing with candle;
(17) Reheating water which has been used in thawer;
(18) Throwing on ground water which contains nitro-glycerine from thawing cartridges;
(19) Rubbing cartridge in hands to complete thawing;
(20) Cartridge left in pocket of garment hung before fire to dry;
(21) Having cartridge and primer near each other when not in use;
(22) Destroying material not considered desirable.

Numbers (2) and (6) are the only cases under Class (*a*) in which danger is to be apprehended from the use of Joveite. The experiment of passing a high-tension spark through it is perhaps as near to natural conditions as it is practicable to get in the laboratory, but the writer is not satisfied that Joveite may not be exploded by lightning.

Under Class (*b*) we have (5) and (21) as the only elements of danger mentioned above which are common to dynamite and Joveite.

This list of "dangers" which the writer has complied is, of course, not complete, but it should be pretty well distributed over the field of ordinary engineering practice.

A rival product to Joveite, previously mentioned, is Masurite, which the writer has not tested personally. It resembles Joveite, and is claimed, doubtless with justice, to be very insensitive to shock, heat, percussion, concussion, an electric spark, etc. The composition is secret, but it contains a large amount of ammonium nitrate. It is claimed to be about as strong, bulk for bulk, as dynamite of corresponding grade, and to be not only flameless but non-inflammable. The cartridge is of paper, as at present made, and is probably subject to the same objections as the early Joveite cartridges before the adoption of cloth fiber. It will not detonate properly when wet, and requires a double-strength primer. An important objection to it is in the fact that the material cakes, and in that condition will not detonate readily, but when being loaded, the cartridges must be thoroughly rolled between the hands. With reference to the claim that this material is non-inflammable, the point suggests itself whether in a large fire, accompanied with much smoke and carbon in suspension, ammonium nitrate would not form a highly explosive mixture. This point the writer will not attempt to discuss.

DISCUSSION.

Mr. Parker. A. McC. Parker, M. Am. Soc. C. E.—The speaker desires to present the results of his experience with Joveite, having used it on the excavation for Pier No. 1 of the Blackwell's Island Bridge, in New York City, where it was represented as being especially advantageous for use because of the proximity of the work to residences. He found it more powerful than ordinary 40% dynamite, so much so that it was necessary to lighten the charges of Joveite. He also found it absolutely unreliable in holes which were at all wet, and in block holes, where water was used in drilling, the time required in swabbing out the holes was so great that its use in such places was abandoned.

In wet holes its use was abandoned entirely after two instances in which, on rounds of four holes each, three went off at the discharge of the battery, while the fourth hole hung fire, long enough in one case for the rock gang to get up within 25 ft. of the blast, and in a previous case while one could ordinarily count three.

The author speaks about the manufacturer having perfected some kind of a water-proof covering, but the covering of the material furnished the speaker did not serve this purpose. The material worked very satisfactorily in dry holes, and was more economical than 40% dynamite.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 954.

THE FILTRATION WORKS OF THE EAST JERSEY WATER COMPANY, AT LITTLE FALLS, NEW JERSEY.*

By George W. Fuller, Assoc. M. Am. Soc. C. E.

With Discussion by Messrs. Allen Hazen, J. P. A. Maignen, C. L. Harrison, J. Waldo Smith, R. S. Weston, George C. Whipple, William B. Fuller, L. L. Tribus, Langdon Pearse, John H. Gregory, L. J. Le Conte and George W. Fuller.

Historical.

The East Jersey Water Company, in 1897, commenced the development of a new source of supply from the Passaic River, at Little Falls, N. J., about 5 miles above Paterson. The pumping station, which was completed in the autumn of 1899, has a capacity of 75 000 000 galls. daily. It is a combination water- and steam-power plant, the pumps being placed between the turbines and steam engines, and connected so that either water or steam power, or both, may be used.

At present, an average daily quantity of about 50 000 000 galls. of water is pumped at this station. Approximately, this quantity has been pumped regularly since November, 1899, and supplied to cities having an aggregate population of about 450 000. About 30 000 000 galls. daily are supplied to Jersey City, in accordance with a temporary contract with the Water Company which terminates at the end of 1903, following the completion of the new gravity water supply now

* Presented at the meeting of April 1st, 1903.

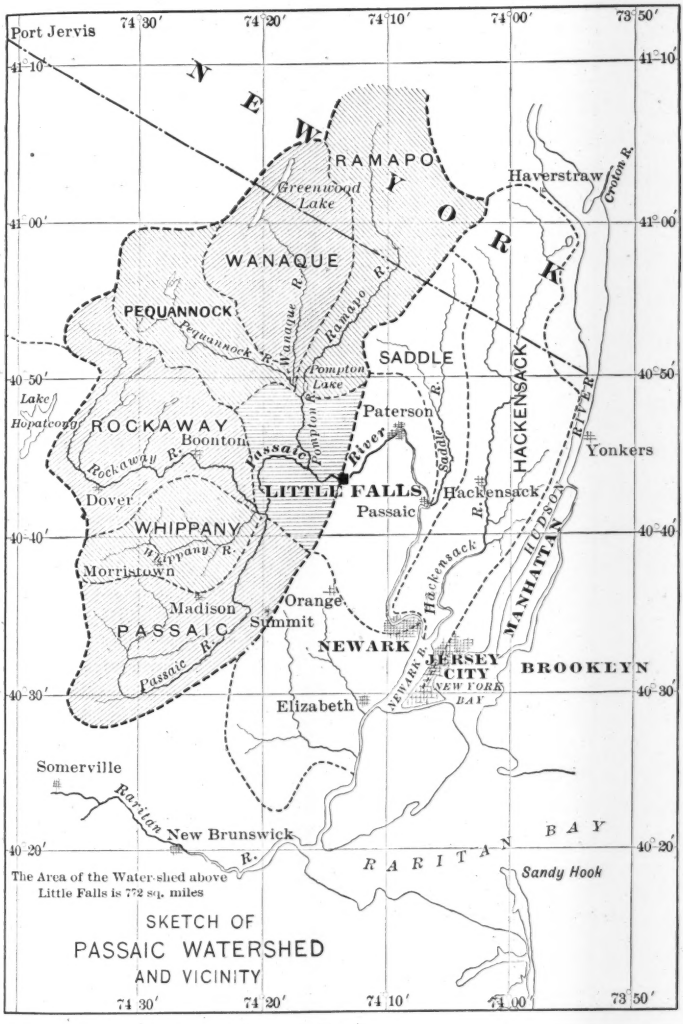

Port Jervis
74° 30′
74° 20′
74° 10′
74° 00′
73° 50′
41° 10′
41° 00′
40° 50′
40° 40′
40° 30′
40° 20′
NEW YORK
RAMAPO
Greenwood Lake
Haverstraw
Croton R.
WANAQUE
Wanaque R.
Ramapo R.
PEQUANNOCK
Pequannock R.
SADDLE
Pompton Lake
Lake Hopatcong
ROCKAWAY
Boonton
Rockaway R.
Passaic R.
Pompton R.
Paterson
Saddle R.
HACKENSACK RIVER
Yonkers
LITTLE FALLS
Hackensack
Passaic
Dover
WHIPPANY
Whippany R.
Morristown
Madison
Orange
Summit
PASSAIC
Passaic R.
NEWARK
Hackensack R.
HUDSON
MANHATTAN
JERSEY CITY
NEW YORK BAY
BROOKLYN
Elizabeth
Newark R.
Somerville
Raritan R.
New Brunswick
BAY
RARITAN
Sandy Hook
The Area of the Water-shed above Little Falls is 772 sq. miles
SKETCH OF
PASSAIC WATERSHED
AND VICINITY

FIG. 1.

being constructed for that city on the Rockaway River, near Boonton, N. J. About 15 000 000 galls. daily are supplied from this station to the cities of Paterson and Passaic. At the close of the Jersey City contract, filtered water from Little Falls will be supplied, to several towns and water companies, through the conduit now used to deliver river water to Jersey City. Among these consumers are Montclair, West Orange and Glen Ridge, which now receive their supply from the surplus of the Pequannock system, in accordance with arrangements made by the East Jersey Water Company with the City of Newark. After the present year, in the neighborhood of 25 000 000 galls. of filtered water daily will probably be furnished from Little Falls.

The water-shed of the Passaic River, at Little Falls, has an area of 772 sq. miles. A large part of two important tributaries of the Passaic is already appropriated for municipal supplies, namely, 63 sq. miles of drainage area of the Pequannock River, which is the source of supply of the City of Newark, and 118 sq. miles on the Rockaway River, above the intake for the works now being built for Jersey City. Some of the more important features of interest in connection with the Passaic water-shed are indicated in Fig. 1.

There are no towns or cities discharging sewage into the Passaic River within some 20 miles of the intake at Little Falls. The only places on the water-shed having sewerage systems are Suffern and Summit, the sewage of the latter being filtered before it reaches the river. There are, however, quite a number of towns and small cities, including Chatham, Madison, Morristown, Boonton and Dover, where there are public water supplies, and where some sewage may reach the stream indirectly, especially following heavy rains.

In its sanitary character the water of the Passaic River at Little Falls is ordinarily very satisfactory, as is shown by numerous analyses and by the typhoid-fever records of the communities which have been supplied with that water during the past three years. The average annual death rate from typhoid fever during the past three years, in Jersey City, Paterson, Bayonne and Passaic, is about 20 per 100 000 inhabitants, and in no case has it exceeded 23 for a single year.

The Passaic River water at Little Falls is not muddy, comparatively speaking, although, after heavy freshets, it carries from 25 to 100 parts per million of suspended matter. At times the water is very noticeably colored, due to dissolved vegetable matter coming from

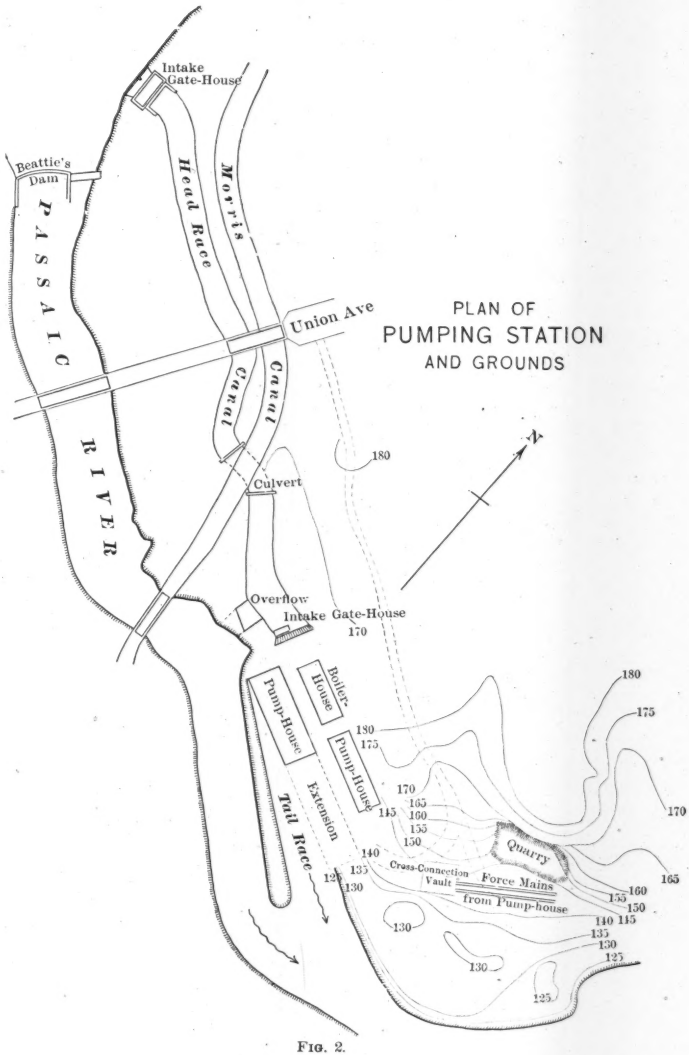

Intake Gate-House
Beattie's Dam
Head Race
Morris
PASSAIC RIVER
Union Ave
Canal
Canal
PLAN OF
PUMPING STATION
AND GROUNDS
Culvert
Overflow
Intake Gate-House
Boiler House
Pump-House
Pump-House
Extension
Tail Race
Quarry
Cross-Connection Vault
Force Mains from Pump-house
180
175
170
165
160
155
150
145
140
135
130
125

FIG. 2.

several large swamps situated on the upper portions of the drainage area. Frequently, the water contains quite large amounts of amorphous matter, consisting principally of finely divided organic material. Much of this seems to come from the bottom of the stream, as the water flows for a few miles through the Great Piece Meadows, just above the intake, where the river has very little slope and where deposited sediment on the bottom is stirred up by carp and other fish. This finely divided amorphous matter, together with the color which appears in the water, gives it at times what might be called a "dirty" appearance, and causes it to be less desirable for domestic use than the analyses indicate.

With the view of making the water thoroughly satisfactory in appearance, and to guard against the effect of the accidental pollution which may be possible occasionally, the Water Company investigated the feasibility of filtration works. A preliminary report on the subject was made by the writer in May, 1900.

Before considering this matter in detail, it will be well to give a general description of the pumping station and immediate vicinity. The pumping station was described in *Engineering News* of August 3d, 1899, in which the principal details may be found. In brief, it may be said that the river water, for both power and water-supply purposes, is conveyed from the river above the Beattie Dam to the intake gate-house near the pumping station through a head-race canal, 1 400 ft. in length and 60 ft. in width. It terminates in a fore-bay, at the side of which is a spillway, and at the end are the penstocks and other conduits leading to the turbine wheels and to the pumps.

The elevation of the water in the head-race canal is normally about 157. In the river below it averages about 122, giving, ordinarily, a fall of about 35 ft. for power purposes. The floor of the pumping station is at Elevation 132, which is also the elevation of the suction chamber of the pumps. To the north of the pumping station is a cliff of trap rock overlying brown stone, the elevation of the surface being in the neighborhood of 180.

The site of the pumping station and power-house was reclaimed from the original river-bed. As will be seen from Fig. 2, a plan of the station and grounds, the river turns to the north just below, leaving an area of less than 2 acres between the river and the force mains, the elevation of the surface of which was in the neighborhood of 130.

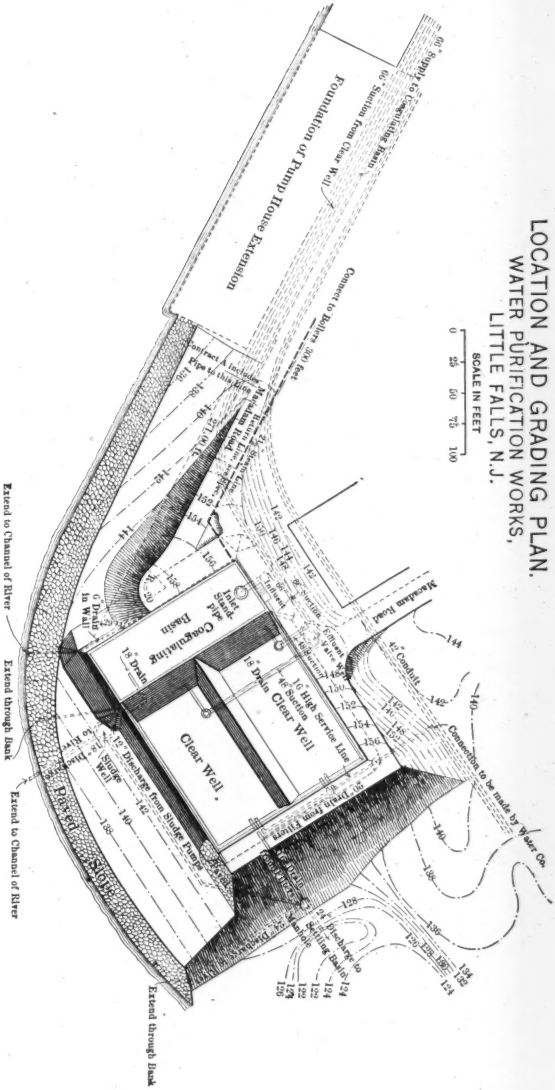

LOCATION AND GRADING PLAN.
WATER PURIFICATION WORKS,
LITTLE FALLS, N.J.
SCALE IN FEET
0 25 50 75 100
Foundation of Pump House Extension
Connect to Boilers 300 feet
Macadam Road
Coagulating Basin
Inlet Stand-Pipe
Clear Well
Clear Well
Paved Slope
Extend to Channel of River
Extend through Bank
Extend to Channel of River
Extend through Bank

FIG. 3.

It was recommended that the filtration works be of the American, or mechanical, type, partly on account of the great desirability of removing the high amount of color which the river water possesses at times, and especially on grounds of economy. It was possible to construct a mechanical filter plant on the small area of ground below the pumping station, through which water might pass by gravity from the head-race canal and back to the suction of the main pumps. If a sand-filter plant had been installed, it would have involved the expense of an additional pumping station to lift the river water to a suitable site upon the cliff above.

The Water Company, in June, 1900, requested the New York Filter Manufacturing Company and the Continental Filter Company, shortly afterward consolidated as the New York Continental Jewell Filtration Company, to submit outline plans and general estimates of cost for this project. These were submitted to the Water Company in September, 1900, and were referred to the writer, who was requested to supervise for the Water Company the preparation of detailed plans by the Filtration Company, and also to prepare specifications. It is gratifying to record that the Water Company instructed the writer not to spare expense in making the plant capable of giving thoroughly efficient service. Mr. Charles L. Parmelee, Chief Engineer of the Filtration Company, had the immediate charge of the preparation of the plans. Upon their construction features the writer had the assistance of W. B. Fuller, M. Am. Soc. C. E., who, later, was appointed by the Water Company as Resident Engineer in charge of the construction work. The entire project was designed and built under the direction of J. Waldo Smith, M. Am. Soc. C. E., Chief Engineer and Superintendent of the East Jersey Water Company. With the exception of the machinery and the operating devices, which were designed by the Filtration Company, the design of this plant was the result of numerous conferences and discussions between the representatives of the Water Company and the Filtration Company.

These works, with few exceptions, were built by contract. All excavation and masonry work in the coagulating basin and clear-water basin, grading, etc., was done by the T. A. Gillespie Company, of New York and Pittsburg; the filter tanks and the entire superstructure were built by Mr. Joseph Sharpe, of Paterson, sub-contractor under the Gillespie Company; and the entire equipment of the filters, includ-

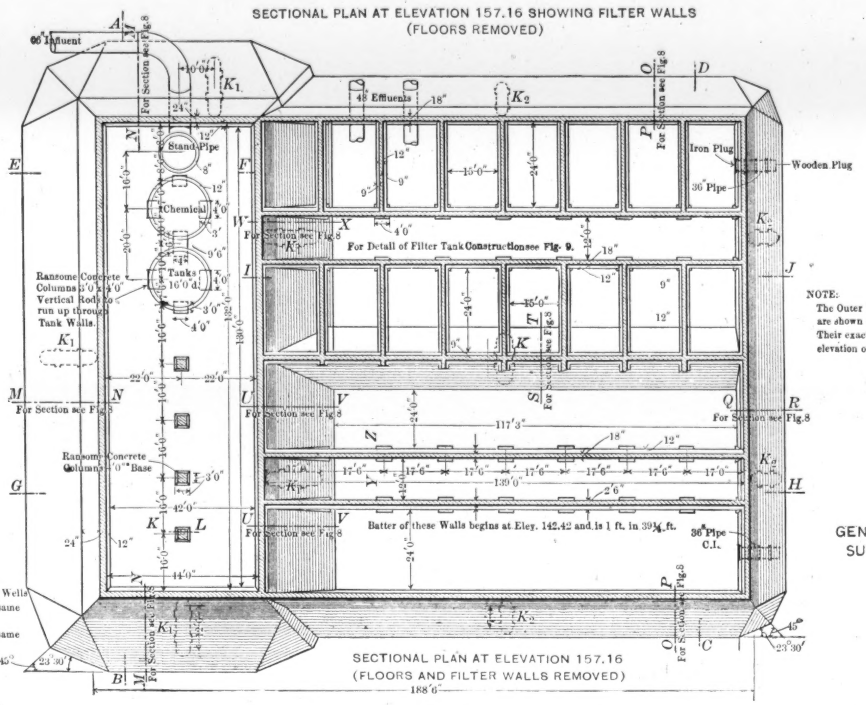

SECTIONAL PLAN AT ELEVATION 157.16 SHOWING FILTER WALLS
(FLOORS REMOVED)
66" Influent
48" Effluents
Stand Pipe
Chemical
Tanks
Ransome Concrete Columns 2'0" x 2'0"
Vertical Rods to run up through Tank Walls.
Ransome Concrete Columns 3'0" Base
For Section see Fig. 8
For Detail of Filter Tank Construction see Fig. 9.
Iron Plug
Wooden Plug
36" Pipe
Batter of these Walls begins at Eley. 142.42 and is 1 ft. in 39¼ ft.
36" Pipe C.I.
NOTE:
The Outer Toes of all Walls and Posts are shown approximately only.
Their exact position depends upon the elevation of the Rock.
NOTE:
K-K are Expansion Wells
All K1 Wells have same dimensions.
All K2 Wells have same dimensions.
SECTIONAL PLAN AT ELEVATION 157.16
(FLOORS AND FILTER WALLS REMOVED)
188'6"
GENERAL PLAN OF SUBSTRUCTURE

FIG. 4.

ing piping, valves, strainer systems, machinery and devices for applying the coagulant and operating the filters, was furnished and erected by the Filtration Company.

Construction work was begun early in April, 1901, and at the end of that year all masonry work, pipes within the walls of the coagulating basin and the clear-water basin, the filter tanks, and the floor of the superstructure, were completed. The walls of the superstructure were barely started. The completion of the buildings proceeded very slowly, due to several interruptions by strikes, etc., and it was not until May, 1902, that the Filtration Company commenced the equipment of the filters. The latter were practically completed by August 1st, 1902; but, owing to delays in securing filter sand, the plant was not placed in service until September 4th, 1902. Since that date the filters in the north wing have been in service regularly, and no unfiltered water has been delivered to consumers in Paterson or Passaic.

The filters in the south wing have not been placed in service, and will not be until after the termination of the temporary contract with Jersey City.

General Description of the Filtration Works.

These filtration works, which have a nominal net capacity of 32 000 000 galls. daily, and are capable, at least for short periods, of yielding 48 000 000 galls. daily, occupy an area of 178 x 219 ft., measured on the outside lines of the foundation walls. The structures are of concrete, with the foundations upon rock at an average elevation of 112. As the flow line in the coagulating basin and in the filters is but a little less than that in the head-race canal (157), it is seen that the structures are relatively very deep, owing to the peculiarities of the site. Views of the works are shown in Plate XXXVI.

At the west end is the coagulating and subsiding basin, 130 ft. long, 42 ft. wide and 43 ft. deep on inside lines, having a capacity of about 1 750 000 galls.

At the east end the lower portion of the structure contains a clear-water basin in two compartments. Each, on an average, is 124 ft. long, 58 ft. wide and 29 ft. deep to the maximum flow line for the filtered water. The total capacity of the clear-water basin is about 3 500 000 galls. Fig. 3 is a general plan of the coagulating basin and clear-water basin.

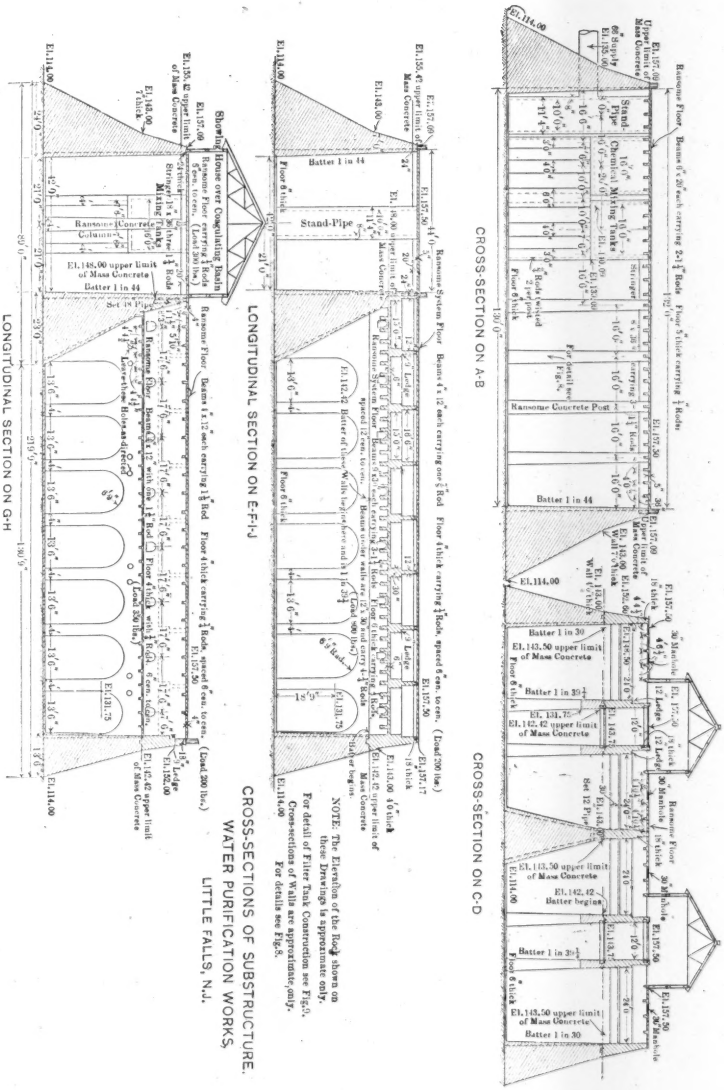

CROSS-SECTION ON A-B
CROSS-SECTION ON C-D
LONGITUDINAL SECTION ON E-F-I-J
LONGITUDINAL SECTION ON G-H
NOTE: The Elevation of the Rock shown on these Drawings is approximate only.
For detail of Filter Tank Construction see Fig. 9.
Cross-sections of Walls are approximate only.
For details see Fig. 8.
CROSS-SECTIONS OF SUBSTRUCTURE.
WATER PURIFICATION WORKS.
LITTLE FALLS, N.J.

FIG. 5.

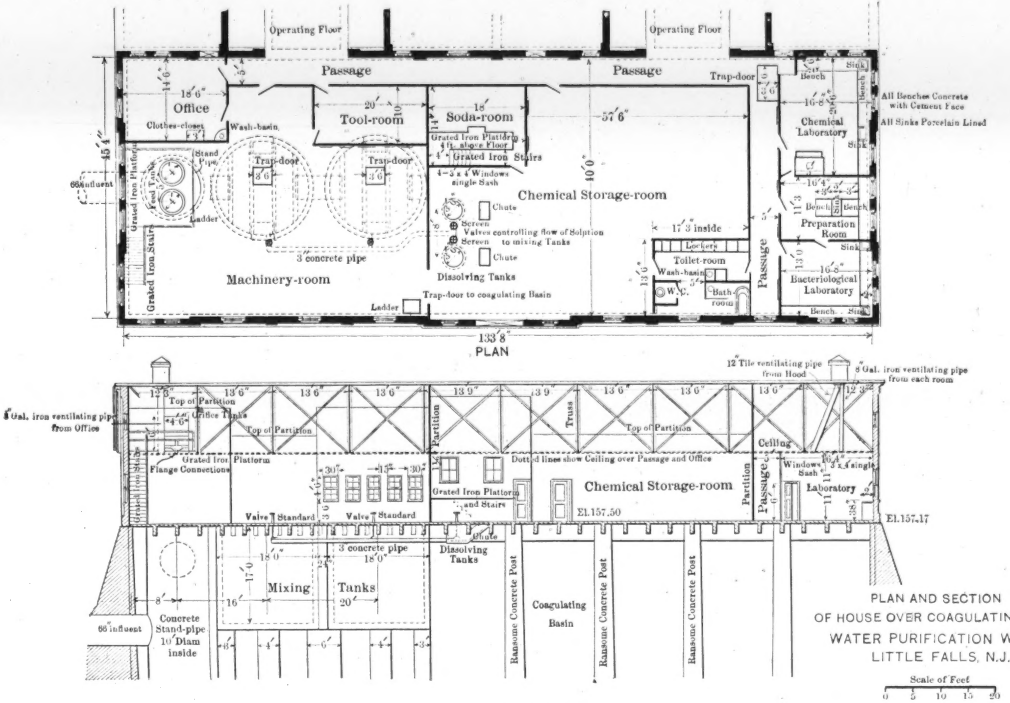
Above the clear-water basin there are thirty-two rectangular, concrete, filter tanks, 24 x 15 ft., and 8 ft. deep, arranged in four rows of eight filters each. The total area of filtering surface is 11 520 sq. ft. Between each pair of rows of filters there is a pipe gallery, in which the main pipes, with branches to the adjoining filters, are placed. This gallery is about 12 ft. wide and 13.5 ft. high, inside. The ends of the filter tanks form the upper portion of the walls of the galleries. The lower portion is formed by walls which extend to the bottom of the clear-water basin, and form a support for the filter floors. The lower portion of these walls is arched out. A sectional plan and cross-sections of the substructure are shown in Figs. 4 and 5.

Over each pipe gallery there is a platform, at a level slightly above that of the water in the filter tanks, and on which the attendants stand when operating the filters. Over each of these platforms, and extending for a width of about 6 ft. on either side, is a building. These two buildings, each about 140 x 30 ft., are called the filter houses, and form two wings of the main building, with which they connect. The remaining portion of the filters is covered with a flat concrete roof with a manhole over each filter, through which materials may be added or removed.

The coagulating basin is covered with a flat concrete roof, which forms the floor of the main building. This building is 132 x 46 ft., and contains the machinery-room for the rotary blowers, pumps and devices for applying coagulant, storage for the same, and also the laboratories, offices, tool-room, wash-rooms, lockers, etc. Figs. 6 and 7 show a plan and section of the buildings.

All machinery is operated by electric motors, the current for which, as well as for the electric lights, is furnished by generators located in the main pump-house.

River water is taken from the head-race canal, and is delivered to the filtration works through a 66-in. steel main discharging into a concrete stand-pipe, 10 ft. in diameter, located at the north end of the coagulating basin. In this stand-pipe the water is treated with a solution of coagulant, and, after thorough mixing by the natural agitation in the stand-pipe, it passes from the bottom of the same into the coagulating basin and thence to the south end, where, near the surface, it is collected in a perforated pipe, through which it passes to the filters. It is possible to by-pass the coagulating basin,



PLAN AND SECTION
OF HOUSE OVER COAGULATING BASIN
WATER PURIFICATION WORKS,
LITTLE FALLS, N.J.

FIGS. 6 AND 7.

and deliver the water from the upper portion of the stand-pipe through a pipe connecting with the main inlet pipes to the filters. After passing through the filters the water enters the clear-water basin, from which it flows through a 66-in. steel suction main, encased in concrete and leading to the main pumps. Branch suction pipes extend from the sump in either compartment of the clear-water basin, with necessary valves in an effluent-valve well, located outside the basin where the branches join the main line. Filtered water from the entire plant may be taken from either compartment independently of the other.

Necessary facilities are also provided for cleaning out the coagulating basin, including a pump located in a sludge well to the south of the basin. Arrangements are made by which at times of low water, if need be, the sediment removed from the basin, as well as that from the discharged wash-water, may be settled out in a catch-basin to the east of the filter plant. The main features of the outside piping are shown in Fig. 3.

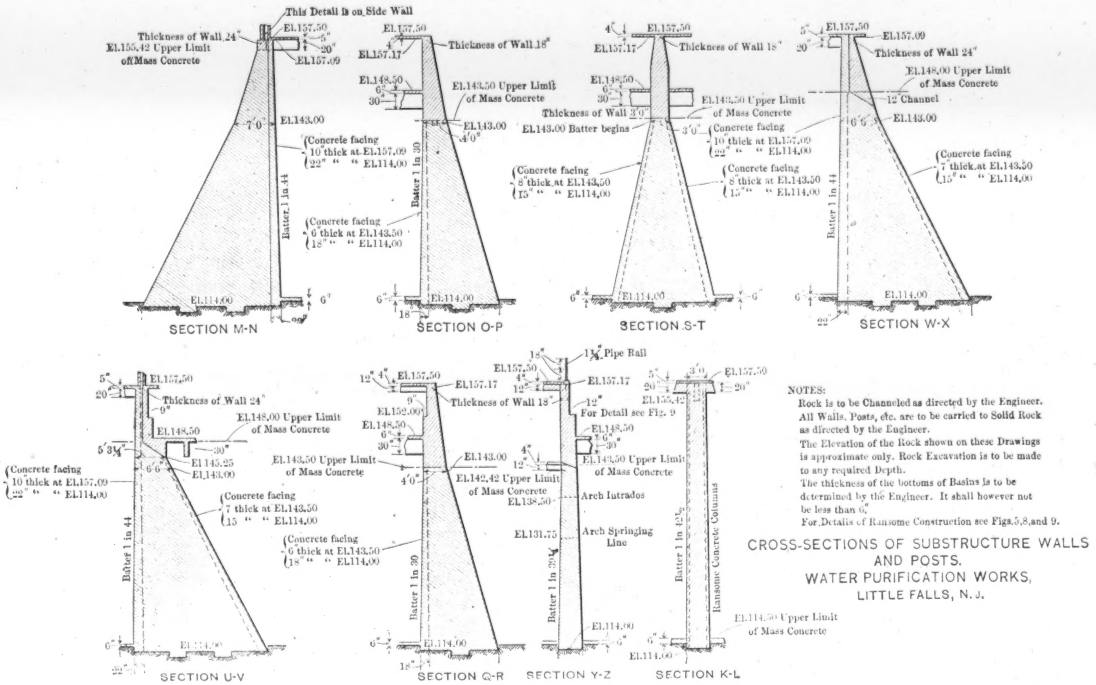
General Features of Construction.

The coagulating basin and clear-water basin are of concrete. Reinforced concrete, after the Ransome system, was used for the construction of the filter tanks, all floors and walls of the houses, and the roof of the filter tanks. No wood was used about the buildings, except in the doors and windows.

The mass concrete in the main walls of the substructure was mixed in the proportion of 1 : 3 : 7. Atlas cement, exclusively, was used for this portion of the work. The gravel and broken stone were graded with much care, the general range in size being from $\frac{1}{4}$ in. to 3 ins. in diameter. The concrete was laid unusually wet. On the inside of the principal walls there is a facing of rich concrete mixed in the proportions of 1 : $1\frac{1}{4}$: 3. Typical sections of the main walls are shown in Fig. 8.

In the main walls, as shown by dotted lines on Fig. 4, there were left seven expansion wells or openings, with the intention of having such cracks as might appear in the walls confined to these places, which, later, would be filled with concrete. A single crack developed at each of four of the wells.

The only crack of importance was one about $\frac{1}{4}$ in. in average



NOTES:

Rock is to be Channeled as directed by the Engineer.
All Walls, Posts, etc. are to be carried to Solid Rock as directed by the Engineer.
The Elevation of the Rock shown on these Drawings is approximate only. Rock Excavation is to be made to any required Depth.
The thickness of the bottoms of Basins is to be determined by the Engineer. It shall however not be less than 6".
For Details of Ransome Construction see Figs. 5, 8, and 9.

CROSS-SECTIONS OF SUBSTRUCTURE WALLS AND POSTS.
WATER PURIFICATION WORKS,
LITTLE FALLS, N. J.

FIG. 8.

width, which extended through the expansion well of the division wall in the clear-water basin, across the floor of the south basin and part way up the outer wall of the latter at the expansion well. This was repaired before water was turned on, and no leaks of consequence were detected in any of the walls of the coagulating basin or clear-water basin when the plant was placed in service. In fact, appreciable amounts of moisture on the outside of the walls were noticeable in only two or three instances.

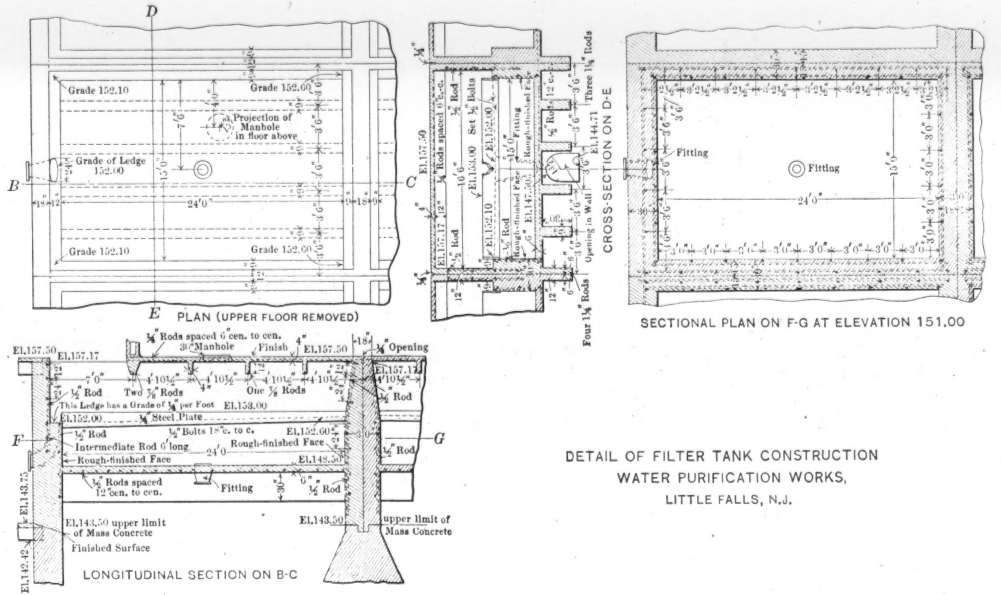
Upon emptying the basins during the past month no cracks were detected in the walls of the coagulating basin, but a very narrow crack was noted opposite the expansion well in the wall separating the coagulating basin from the south compartment of the clear-water basin. It extends some 20 ft. from the bottom, and, under a head of about 40 ft., water was oozing from the lower end at the rate of about ½ gall. per minute.

Each filter tank, 15 x 24 ft. and 8 ft. deep, was built as a continuous box of concrete reinforced with twisted steel rods in each direction, placed as shown in Fig. 9. It was specified that each of these filter tanks when started should be built continuously until completed. The concrete used in these tanks was mixed in the proportions of about 1 : 2 : 4, and was laid very wet. Vulcanite cement was used principally for this portion of the work. All the filter tanks were plastered on the inside with a ¼-in. coat of rich mortar, in the proportions of 1 part of cement to 1 part of sand. The inner walls of the tanks below the sand surface were roughened by stippling with a wire brush before the plastered surface had thoroughly set. In no instance have there been any cracks or leaks in these filter tanks.

The concrete roof over the filters, which was built as a part of each respective tank, is 4 ins. thick, supported by Ransome concrete beams 4 x 12 ins., placed 4½ ins. apart.

The floor of the main building, over the coagulating basin, has a thickness of 5 ins., with Ransome concrete beams spaced 4 ft. apart. One end of each beam is supported by the walls of the basin and the other by a central Ransome concrete girder, 8 x 36 ins., with three 1¼-in. rods. This girder is supported by Ransome concrete columns, 4 ft. square at the base and 43 ft. high.

The tanks for preparing solutions of sulphate of alumina, of which there are two, each 17 ft. deep and 16 ft. in diameter, are built of Ransome concrete, and are placed beneath the floor of the main house.



DETAIL OF FILTER TANK CONSTRUCTION
WATER PURIFICATION WORKS,
LITTLE FALLS, N.J.

FIG. 9.

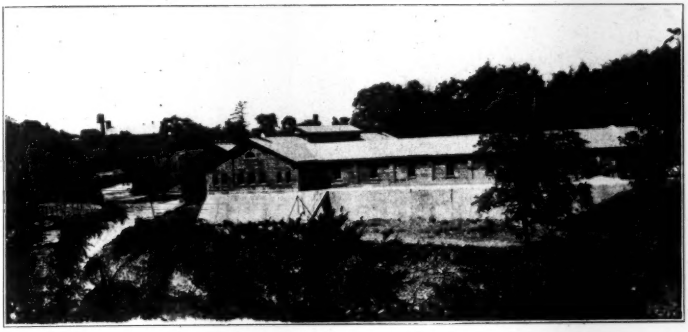
The main house over the coagulating basin, about 46 ft. wide and 132 ft. long, has hollow concrete walls 13 ft. high. The slate and tile roof is supported by steel trusses. The two filter houses, forming wings to the main house, are also built with hollow concrete walls. In order to make the buildings harmonize with the pump-house, the cement was colored to resemble brown stone.

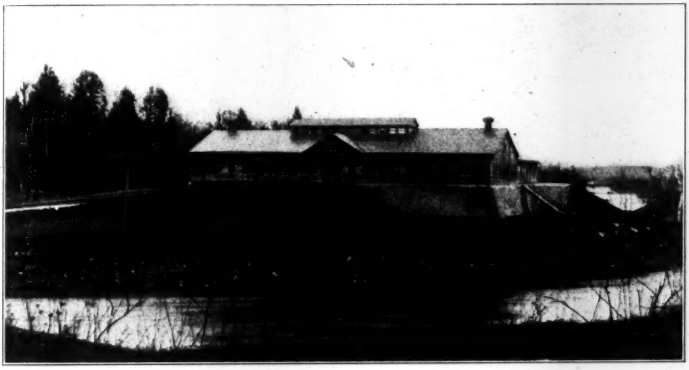
Expansion joints in the walls of the buildings were provided, back of each pilaster, with the view of preventing cracks. Very few cracks have appeared elsewhere.

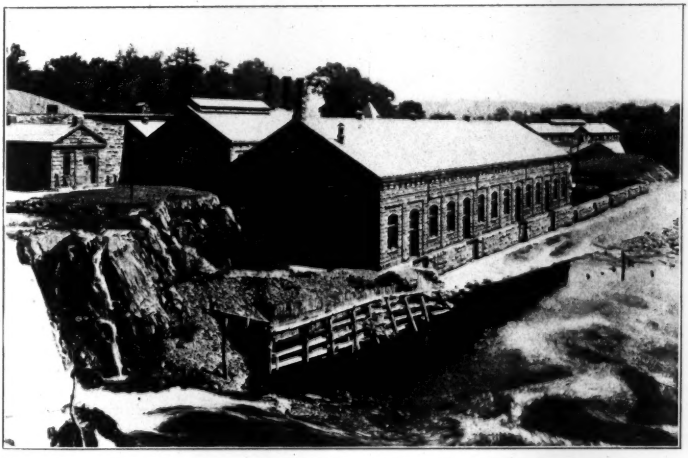
Regarding the specifications, it may be of interest to state that the Water Company furnished the cement for the substructures, which were built strictly in accordance with the plans, the Water Company taking full responsibility as to stability and water-tightness. The superstructure, including all tanks, was built under a guaranty in these respects. The contractor furnished the cement, and had the option of increasing the quantities of concrete and metal above those shown in the plans, which were the minimum permitted by the Water Company. The guaranteed safe loads per square foot were: 800 lbs. for the floor of the filter tanks, 200 lbs. for the roof of the filters, 350 lbs. for the floor of the pipe gallery, 200 lbs. for the operating platform, and 300 lbs. for the floor of the main building. As to the filter equipment, the Filtration Company guaranteed specified efficiencies for the machinery, and that all devices should perform successfully the work for which they were designed, when judged from a strictly physical or mechanical standpoint. The Water Company took full responsibility as to the behavior of the plant in treating the water.

Description of the Details of the Principal Devices.

Application of Coagulant.—Sulphate of alumina is used as the coagulating chemical. It is received in barrels in carload lots, and stored in the main building. The dry chemical is weighed and dumped into the chutes leading to the dissolving tanks situated below the floor in the store-room. In these tanks saturated solutions are prepared, and, to accelerate the dissolving action, heavy bronze stirrers are provided, which revolve slowly in the mass of chemical in the tanks. From these dissolving tanks, each of which has a capacity of 252 galls., the solutions flow through cement pipes to the mixing







PUMPING STATION AND FILTRATION PLANT, LITTLE FALLS, N. J.

tanks. These are of concrete, circular in plan, 17 ft. deep, and each holding about 25 000 galls. The saturated solutions are here diluted to any desired degree by the addition of filtered water. Uniformity in strength of solutions is maintained by frequent stirring by air agitation, the air being supplied from rotary, belt-driven blowers, about 75 cu. ft. of free air per minute being distributed through a radial system of air-pipes at the bottom of each tank.

The solutions are lifted from the mixing tanks, by centrifugal pumps, to the orifice tanks, which are in duplicate, built of concrete, 4 ft. in diameter, of a capacity of 340 galls. each, and situated on a platform in the machinery-room, with the flow line at Elevation 170, or about 13 ft. above the water line of the coagulating basin.

The centrifugal pumps are of standard pattern, cast of special bronze, and are operated by direct-connected electric motors. All pipes, valves and fittings are of hard rubber. All devices are in duplicate, only one set being used at a time.

The quantity of solution pumped from the mixing tanks to the orifice tank may be regulated in the latter, approximately, by a piston valve operated by a float, but it is always kept slightly in excess of the amount being used, and there is an overflow pipe through which the excess is returned to the mixing tank. In this way there is maintained a constant level in the orifice tank, and hence a constant head on the orifice through which the solution passes from the elevated tank to the raw river water.

As the solution leaves the orifice tank it flows into a concrete funnel on the mouth of a 2-in. pipe, which conveys it to the discharge manifold. The latter is located in the mouth of the main inlet pipe, and is a wrought-iron frame holding a grid of $\frac{1}{2}$-in. brass pipes tapped into a 2-in. brass header. The branches are 6 ins. apart, and each one has $\frac{1}{4}$-in. holes, on 6-in. centers, through which the coagulant solution is discharged. The total number of holes in this discharge manifold is 100. The manifold is hung in vertical slides from the stand-pipe, and can be raised or lowered readily by means of wire ropes and a windlass.

Regulation of Coagulant Feed.—At the bottom of the orifice tank there is a rectangular slot, made of hard rubber and having a fixed width of $\frac{1}{4}$ in. By means of a slide, which works over the face of this orifice, the length of this opening may be adjusted from 0 to 6 ins.

Adjustment is made by a rod, which connects with the slide in the tank and passes through the side of the tank to a frame. A milled wheel in a fixed bearing, with a fine adjusting thread, is used to move the orifice plate. A pointer on the rod, over a fixed scale, indicates the length of the opening, and facilitates adjustment. The orifice is calibrated for the different divisions of the indicator, and a diagram is used to indicate the corresponding flow.

In the original design provision was made for a series of orifice plates, each plate to contain thirty-two orifices, corresponding to the number of filters. In operation it was the intention to plug as many of these orifices as there were filters out of service, and to have different-sized orifices in each of the series of plates, so as to provide a reasonable range in the rate of application of the sulphate of alumina to the water treated. This design was abandoned, partly on account of the interference with each other of the orifices placed fairly near together, and partly on account of changes in the edges of the orifices due to fine granular deposits which would probably accumulate there.

The device which was built is moderately satisfactory, but has given some trouble, chiefly due to inability to secure at all times a volume of flow corresponding to that indicated by the length of opening of the orifice. Some difficulties of a clogging nature were encountered at first, due principally to splinters from the barrels, which passed through the screens first used in the mixing tanks.

In each of the mixing tanks is an automatic recording gauge which makes a constant record of the depth of solution. For periods of several hours, the differences in the level of the solution in the tank, as read from the gauge, give a satisfactory record of the quantity of solution used. Owing to the size of the tanks, however, this does not give an immediate detection of a change in the rate of flow. This information is now obtained by a float in the orifice tank, which rings a gong as soon as the level of the solution in the small tanks drops 1 in. That is, if the flow is interrupted, in degree equivalent to the full flow for less than one minute, the fact is announced by this gong. Changes in the rate of application of the coagulant solution are secured ordinarily by the indicator connected with the calibrated screw for changing the length of the orifice, but at intervals this is checked by means of a small measuring tank holding about 30 galls., and through which the solution passes on its way to the discharging manifold in the mouth

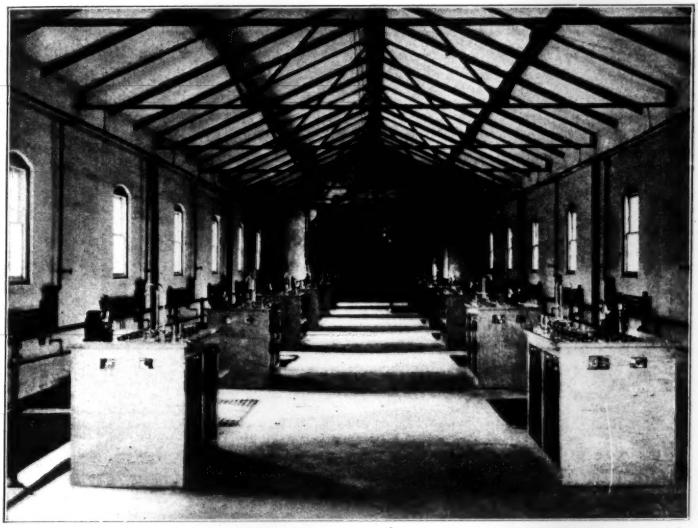


FIG. 1.—OPERATING-ROOM, LITTLE FALLS FILTRATION PLANT.

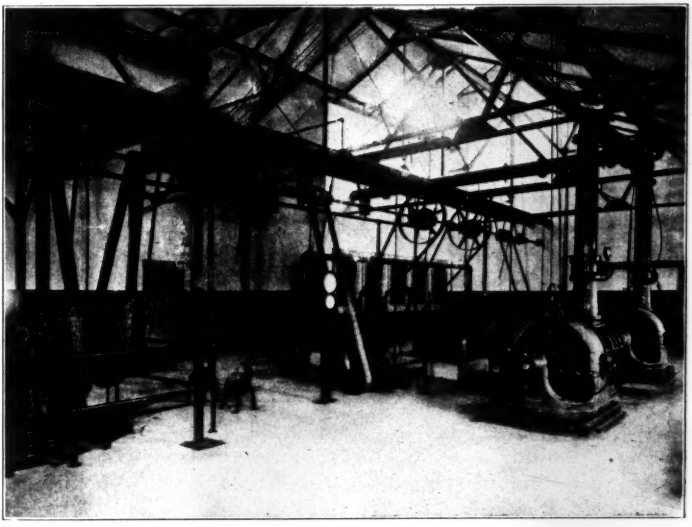


FIG. 2.—MACHINERY-ROOM, LITTLE FALLS FILTRATION PLANT.

of the main inlet pipe. With the devices for controlling the coagulant solution as they now stand, it is considered that this branch of the plant is under satisfactory control.

Application of Soda Ash.—At times of heavy floods the alkalinity of the river water becomes very low, and at rare intervals it is necessary to add some alkali in order to ensure complete decomposition of the applied coagulant. Solutions of soda ash are used for this purpose. They are prepared in iron tanks, 6 ft. in diameter and 6 ft. deep. Both hot and cold water are piped to these tanks, in each of which there is a false bottom of perforated brass on which the dry chemical is placed. The tanks are then filled from below, preferably with hot water, the upward current furnishing sufficient agitation to stir the solution. Ordinarily, the solutions as used contain 5% of soda ash. From the tanks, the soda solution is pumped by a triplex pump operated by an electric motor, and enters the raw water in the main inlet pipe about 175 ft. from its entrance into the coagulating basin. Black-iron pipe is used throughout for the soda outfit. The regulation of the flow of the solution is obtained entirely by the speed of the pump.

Cleaning the Basins.—As the bottom of the coagulating basin and of the clear-water basin is below low water in the river, it is necessary, for purposes of cleaning, to pump out the contents of the lower 6 to 10 ft. In the coagulating basin there is a sump, located as shown on the plans, to which the floor slopes slightly. Cast-iron suction pipes lead from this sump to duplicate vertical centrifugal pumps located in the sludge pump well outside the main structure, as shown in Fig. 3. There is also a suction pipe for these pumps extending to suitable sumps in the clear-water basin. To prevent any admission of water from the coagulating basin to the clear-water basin, the valves from these pipes are designed to be interlocked. The pumps are operated by electric motors set on a platform in the well just above high water. The discharge pipes from the sludge pumps are arranged so as to allow a direct discharge of the sediment into the river, or, if desired, into the catch-basin at the eastern end of the plant, from which the overflow reaches the river after leaving behind the bulk of the sediment.

To facilitate the removal of the last portion of the sediment in the coagulating basin, six hose connections with the high-service filtered-water main are distributed around the basin, about 4 ft. from the

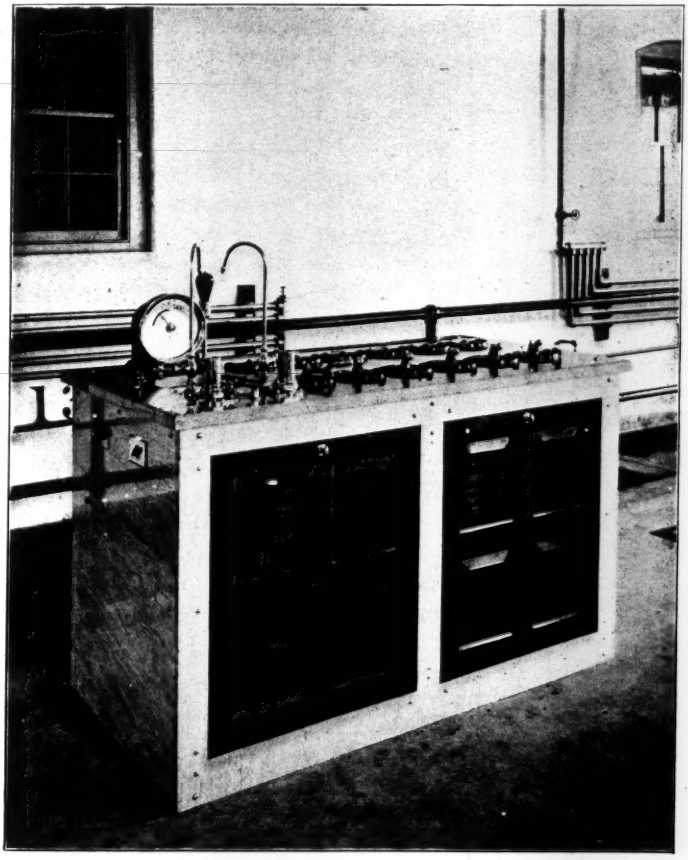
bottom. Thus far, the water for flushing purposes has been obtained by opening the gates at the bottom of the stand-pipe, thus admitting raw river water.

Filter-Strainer System.—The strainer system in the floor of the filter comprises a cast-iron header, oval in section, 12 x 6 ins., running lengthwise of the tank in the center, to which are connected $1\frac{3}{4}$-in. cast-iron laterals, set $6\frac{3}{4\,2}$ ins. from center to center. The laterals are cemented into the header, and extend to the sides of the tank, where their ends are closed with cement plugs. Into the header and the laterals are screwed strainers of the Continental type, on $6\frac{1}{4}$-in. centers, there being 1 316 strainers in each filter tank.

The body of these strainers is made of hard cast brass, and the top of cupped brass plate. In each strainer there are 33 holes, $\frac{1}{16}$ in. in diameter in the top and sides. The neck of the strainer is a $\frac{3}{8}$-in. brass tube, which extends into the cast-iron lateral to within $\frac{3}{4}$ in. of the bottom. This extension tube forms a trap when air is applied, and the air passes from the lateral through a perforation in this extension tube, $\frac{3}{3\,2}$ in. in diameter, and located just below the upper wall of the cast-iron lateral.

The connection to the strainer system from below is through the bottom of the tank at the center, where a cast-iron ring is set in the concrete. The central tee of the strainer manifold is bolted to this ring at the top, and at the bottom are fastened the pipe connections which provide an outlet for the filtered water and the inlet for the water and air used in washing. By means of a special double pipe-casting, air is admitted to the strainer system at the top of the central manifold tee, an internal casting in the pipe connection passing up through the ring casting and into the tee. To the lower end of the opening of this internal pipe is connected the air supply line, which passes beneath the floor of the filter to the main air line in the pipe gallery. The outer portion of this special casting forms a water channel, and is connected with the pipe passing under the floor of the filter to the pipe gallery, and is used as an outlet for the filtered water and an inlet for the wash-water.

The space between the lateral pipes is filled with gravel and covered with a cement surface to give a level floor just below the strainers. The construction was such as to facilitate, in case of repairs, ready removal and replacement. The cement surface was coated with two



AN OPERATING TABLE, LITTLE FALLS FILTRATION PLANT.

layers of brick preservative paint, to prevent the solution of the cement before it had completely set.

The general arrangement of this strainer system is shown in Plate XXXIX. At the ordinary rate of filtration, the linear velocity of the water in the main header of the manifold, as it leaves the filter tank, is about 2 ft. per second. In the laterals, as the water enters the main header, the velocity is about 1 ft. per second. The exit area of the orifices is equal to 0.37 sq. in. per square foot of filtering surface.

The size of the orifices in the strainer system, $\frac{1}{16}$ in., is larger than in the case of most mechanical filter plants now in service, and it is believed that the resulting freedom from clogging, which, in many instances, is characteristic of fine perforations or fine slots, is a distinct advantage. It is necessary, however, with this type of strainer, always to use gravel to support the sand and prevent it from reaching the orifices. The arrangement of this gravel is described under "Filtering Materials."

The total loss of head, including both friction and velocity head, through the strainer system and outlet pipe, at the normal rate of filtration, 2 galls. per square foot per minute, is about 0.7 ft.

Filtering Materials.—On the floor of the filter there are 2 ins. of broken quartz, above which is a 5-in. layer of finer quartz. The object of these quartz layers, as indicated previously, is to protect the strainer system from the entrance of sand into the orifices and through the outlet pipe into the controllers. The coarser of these two gravel layers was passed through a screen having 4 meshes to the linear inch, and was retained on a screen having 8 meshes. Its effective size is 4.4 mm., and its uniformity coefficient is 1.30. The finer gravel layer was screened between 8 and 12 meshes to the inch. Its effective size is 2.00 mm., and its uniformity coefficient is 1.45.

The success of these gravel layers depends upon the selection of materials of such hydraulic subsiding value that they are not unseated when wash-water is applied at the velocities used, and of a size fine enough to prevent the sand from passing through them.

Regarding the filtering sand, the filter tanks in the north wing are the only ones which have as yet been filled. As this was the only portion of the plant to go into service during the first year, it was decided that it would be advisable to try different sizes of filtering sand and then charge the tanks in the south wing at a later date with the

material which was found to give most satisfactory service under the actual local conditions.

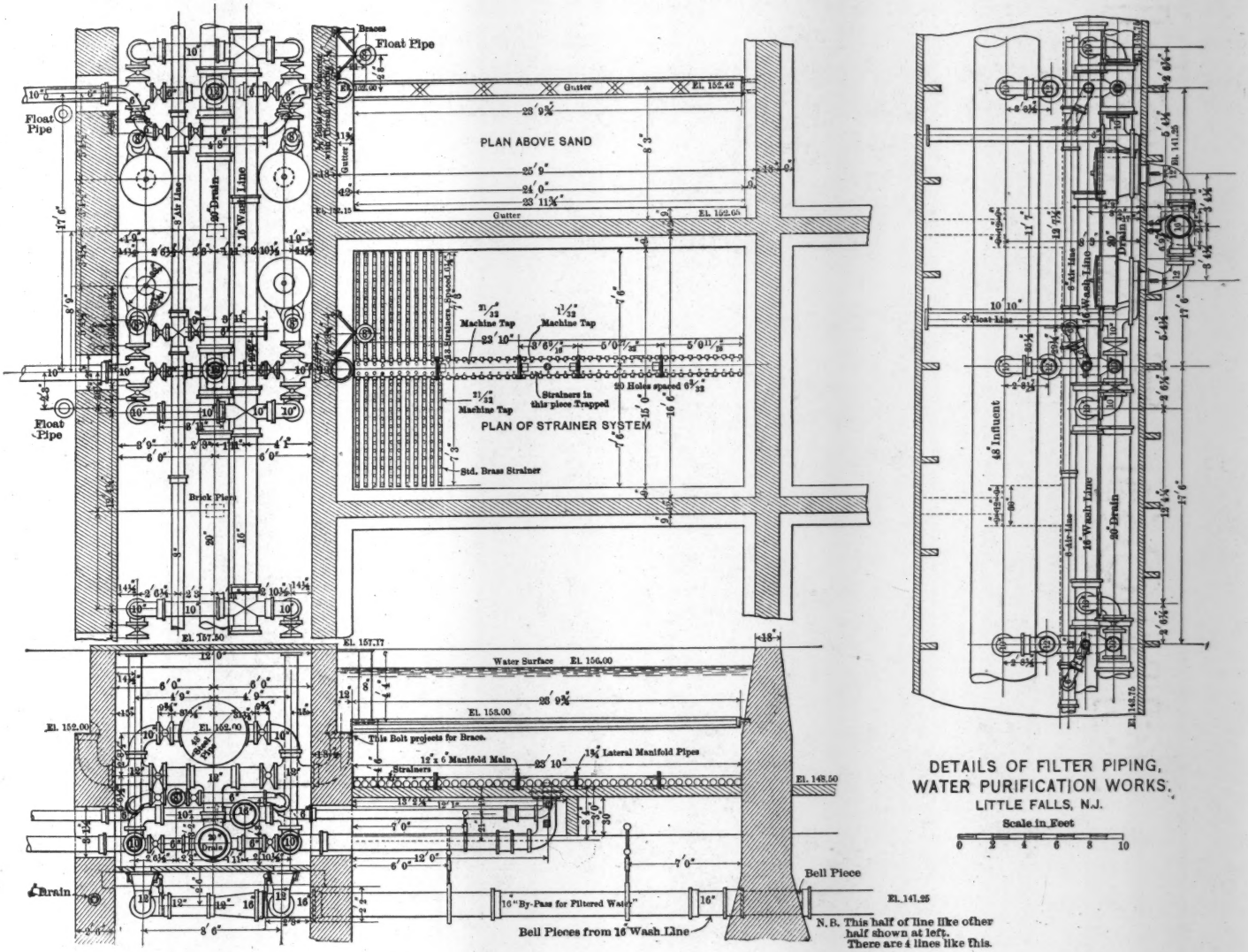
It was specified that the filtering sand, which is 30 ins. in thickness, should have an effective size within the limits of 0.35 to 0.42 mm., with a uniformity coefficient of not more than 1.50. Not more than 1%, by weight, of the sand was allowed to be finer than 0.25 mm., and not more than 0.2% finer than 0.20 mm.

Considerable difficulty was experienced in getting suitable sand. The two sand dealers with whom the contract was placed by the Filtration Company failed to deliver the material, and the commencement of operations was delayed fully one month, during which time the joint efforts of all concerned were devoted to securing suitable sand from any available source. Part of the sand came from near Oyster Bay, Long Island, part from Roslyn, Long Island, and part from Hanover, N. J. The difficulty consisted principally in getting sand from which the fine material was properly eliminated. It was not found feasible, with the screening outfits as built and operated at the several places, to remove the fine material by screening under water. Screening of the sand when absolutely dry seemed to be the only thoroughly successful method of securing the material specified. Sand screening at the several places was watched by representatives of the Water Company, and Allen Hazen, M. Am. Soc. C. E., in the interests of the Water Company, also advised.

The final outcome was that sand containing a considerable excess of fine material was allowed to go into the tanks, and the fine particles were removed by repeated washing of the material in place and scraping of the surface layers. In many cases as much as one-third of the sand as delivered was removed from the filter tanks by scraping. In this way satisfactory results were obtained finally.

As already stated, it was decided to make some differential tests during regular operations, in order to discover the most suitable size of sand for these filters. It was arranged to have two filter tanks charged with relatively coarse material, two others with relatively fine material, and the other twelve tanks in the north wing charged with material fulfilling the original specifications. A summary of the mechanical analyses of the materials in the sixteen filters now in use is given in Table No. 1.

The analyses summarized in Table No. 1 were made during the



DETAILS OF FILTER PIPING,
WATER PURIFICATION WORKS,
LITTLE FALLS, N.J.

Scale in Feet

0 2 4 6 8 10

second month of service of the filters. In December, about ¼ in., on an average, was scraped from the surface of the filters. Analyses now being made indicate that the effective size, on an average, has increased about 0.02 mm. The analyses given in Table No. 1 are representative of the conditions under which the results of operation recorded in this paper were obtained.

TABLE No. 1.—SUMMARY OF THE MECHANICAL ANALYSES OF FILTERING SANDS.

Number of filter.	Effective size, in millimeters. (10% finer than.)	Uniformity coefficient.	PERCENTAGE FINER THAN:	
			0.25 mm.	0.20 mm.
1	0.44	1.32	0	0
2	0.40	1.50	0	0
3	0.37	1.38	0.2	0
4	0.41	1.44	0	0
5	0.38	1.50	0.4	0.1
6	0.41	1.44	0.1	0
7	0.35	1.50	0.5	0.2
8	0.42	1.43	0.4	0.1
9	0.40	1.42	0.5	0
10	0.41	1.46	0.4	0.2
11	0.37	1.41	0.3	0.1
12	0.46	1.50	0.4	0
13	0.39	1.50	0.2	0.1
14	0.39	1.50	0.2	0.1
15	0.39	1.46	0.2	0.1
16	0.38	1.50	0.1	0.2

The loss of head due to friction in 30 ins. of sand of normal size (effective size 0.41 mm., and uniformity coefficient 1.45) when clean is 1.1, 1.7 and 2.6 ft., respectively, for rates of filtration of 80, 125 and 185 millions of gallons per acre daily. For the coarse sand (effective size 0.46 mm., and uniformity coefficient 1.40) the loss is 1.4 ft. for a rate of 125 000 000 galls. per acre daily.

Wash-Water Appliances.—Wash-water is ordinarily applied to the filters by centrifugal pumps operated by direct-connected motors, and which take their supply from the clear-water basin below the filters. One centrifugal pump and motor is placed in the bottom of each pipe gallery. These pumps have a capacity of 3 000 galls. per minute. The piping is cross-connected, so that either pump may be used for washing one filter at a time in either wing. The wash-water lines are also connected with the force mains leading from the pumping station to the distributing reservoirs in the districts supplied with filtered water. On this connection to the high-pressure

line are pressure-reducing valves. As the filters are now operated, a head of about 25 ft., measured from the floor of the filter tanks, is maintained in the main wash-water line.

When the wash-water is applied to the filters it enters the filtered-water outlet pipe, passes through the manifold pipe of the strainer-system, and thence through the strainers themselves into and through the sand layer. The dirty wash-water is removed, in part, through lateral gutters about 60 sq. ins. in cross-section, placed along the sides of each filter tank, and formed by a steel plate attached to the ledge provided in the masonry walls. There is also a central gutter, of about 85 sq. ins. in cross-section, extending from the rear of the tank and discharging into the front gutter about 140 sq. ins. in cross-section, extending across the end of the filter, and which receives also the flow of the lateral gutters. The distance from the top of each of these gutters down to the surface of the sand layer, when the filter is in regular service, is about 12 ins.

The dirty wash-water leaves the filter through the inlet pipe, to which there is a branch leading to the sewer. The wash-water system was designed for an application of wash-water at a vertical velocity of about 1 ft. per minute (equal to about 7½ galls. per square foot per minute). The carrying capacity of the lateral and central gutters is somewhat less than was expected, and when the wash-water is applied at the foregoing rate a weir action is not obtained for the full length of the lateral gutters. It was found, however, owing to the fineness and low specific gravity of the materials removed from the water by filtration, that lower velocities for the wash-water are more advantageous than was expected, from experiences with filters treating muddy waters in the South and West. Accordingly, these gutters have worked reasonably well, under the existing conditions. It is planned, however, to raise them some 3 or 4 ins. and increase correspondingly the thickness of the sand layer, as soon as additional filtering material may be conveniently obtained.

The devices for facilitating the operation of washing the filters, and the general procedure which is being followed, are considered further on.

Agitation of the Sand Layer.—Compressed air, under a low pressure, is used in agitating the sand layer and facilitating the removal of the accumulated materials during washing, in place of the mechanical stirring devices with rake arms, such as have been used in the majority

of filter plants now in service. In the machinery-room there are two No. 3, Root's rotary blowers, of standard make, direct-connected with electric motors. Each has a guaranteed capacity of 1 500 cu. ft. of free air per minute, under a pressure of 5 lbs. From the main air line, running lengthwise of each pipe gallery, there is a branch to each filter, passing beneath the filter floor and entering the special casting below the center of the floor of the filter. The air is delivered at the top of this casting, thence it passes through the manifold piping system to the trapped strainers, next through a small orifice in the strainer-tube extension near the top of each lateral pipe, and thence through the several strainers. The rate of application of air used ordinarily is about 1 000 cu. ft. per minute, under a pressure of 3 lbs. The distribution of the air through all the strainers is uniform to a satisfactory degree, and it agitates the sand bed efficiently, causing the grains to be rubbed together, and with facility freed from the films of organic and other matters which surround the individual grains.

In no instance is agitation with air used at the same time that the wash-water is applied to the filters. The application of air forms the first step in the process of cleaning, and then, after the wash-water has been applied to secure fairly thorough cleaning, the air has been again applied for about one minute to effect further cleansing. During the application of air the water stands in the filters about 4 ins. above the top of the sand surface, or 8 ins. below the top of the overflow gutters. The applied air raises the sand layer about 3 ins., but it does not cause the entire mass to become floated as in the process of washing. Water is always used after the last application of air, and thus the sand layers are freed from any entrained air. The application of air in the manner described does not effect any appreciable grading of the sand grains.

Filter Piping and Connections.—Plate XXXIX shows a plan and section indicating the size and general arrangement of the piping, all of which is placed within the pipe gallery, together with the connections to the filters. The sizes of the leading pipes are as follows:

Main raw-water supply	48 ins.
" wash-water supply	16 "
" air supply	8 "
" drain	20 "
Individual filtered-water outlet	10 "
" raw-water inlet	12 "
" air line	6 "

The main inlet pipe is of riveted steel, and is carried on hangers attached to the Ransome beams supporting the operating floor. All other pipe is of cast iron. Flange valves were used throughout, but hub and spigot joints were put in wherever possible, both on account of cost and the greater ease of erection and connection to the masonry structures. It was the aim, also, to distribute the flange and hub connections so that in the event of a break the broken piece would be most easily removed.

Effluent Controller.—Each filter is provided with an automatic controller, of the well-known Weston type, consisting essentially of a moving orifice operated by a float in an open compartment. The water enters the controller through butterfly valves, which are operated by the float. The action of these controllers is to maintain a uniform rate of discharge, independent of the head on the outlet pipe. Accordingly, the filters are always operated during filtration with the valve on the outlet pipe wide open, and the flow is controlled automatically by this device.

Orifice discs of three different sizes are provided with each controller, giving yields of about 1 000 000, 1 250 000 and 1 500 000 galls. per filter per 24 hours, respectively. There are also a few special discs to give a daily yield of 650 000 galls.

The head lost in these controllers, as measured from the water level in the outlet stand-pipe (when the float in the controller is seated) to the top of the pipe gallery floor, is about 2.5, 3.0, or 4.0 ft., when the yields of the filters are 650 000, 1 000 000 or 1 500 000 galls. daily, respectively.

These controllers are placed in the bottom of the filter gallery, and discharge the filtered water through an outlet pipe directly into the clear-water basin below. By means of a galvanized-iron funnel and cross-connection pipe, the water from any filter may be discharged into the opposite compartment of the clear-water basin when desired.

Hydraulic Valves.—All the valves on the filter piping are of Rensselaer make, are generally light-weight, double-disc gate-valves, and are operated by hydraulic cylinders. The valves on the wash-water line are all heavy weight. The water to operate these cylinders is furnished by a separate, high-service line, the connections from which are controlled by special four-way cocks. They are operated by levers, with indicators showing the position of the valves, conveniently

located on the operating table in front of each filter on the platform above the pipe gallery.

Loss-of-Head Gauges.—On each operating table there is a loss-of-head gauge, the dial of which is operated by a float in the water above the sand layer in the filter, and the pointer of which is operated by a float in a small stand-pipe connected to the outlet pipe through which the filtered water passes to the controller. These gauges, which were designed and made by the Filtration Company, are somewhat novel, in that there is an automatic adjustment of the zero point of the gauge to different water levels in the filters. By means of this adjustable dial the reading of the pointer gives the frictional resistance, or loss of head, in the filter at any time. Electrical connection is made when the loss of head reaches the maximum, so that a bell is rung and an electric light is turned on, thus warning the operator that it is time to wash the filter.

Available Head.—The gross head available, measured from the top of the filter tanks to the maximum water level in the clear-water basin, is 14 ft. Ordinarily, the water level on the filters is kept about 1 ft. below the top of the filter walls, giving an available head of 13 ft.

In a filter containing normal sand, and operated at the regular rate (1 000 000 galls. per 24 hours), the loss of head, directly after washing, averages 2.3 ft. Adding this to the head lost by the controller, there is left a net effective head of 7.7 ft. for overcoming the friction caused by the accumulations of sediment, etc., in the sand layer. With a filter containing coarse sand (0.46 mm. effective size), and operated at the regular rate, this effective head is 8.0 ft. With a filter containing normal sand, and operated at a rate of 1 500 000 galls. per 24 hours, the net effective head is 5 ft.

Arrangement of Devices for Operating the Plant.—Unusual attention was given to making the operation of this plant as automatic as practicable, with provisions for indicating to the man in charge the status of the various operations at all times.

Mention has already been made of the devices in connection with the preparation and regulation of the flow of the chemical solutions, the automatic filter controllers, hydraulic cylinders for the operation of the valves, and the loss-of-head gauges. In addition to these the detailed arrangements include gauges for indicating the water levels in the coagulating basin and clear-water basin, and devices for sampling

the water as it passes through the plant. In the general office are two glass cylinders through which pass constant streams of raw and filtered water.

Each filter is provided with an arrangement by which a sample of filtered water from it may be collected readily at any time. In the pipe gallery opposite the outlet pipe of each filter is a small Pelton water-wheel operated from the high-service line. This wheel operates two ¼-in. centrifugal pumps, the suction of one of which is in the filter outlet pipe, and the other in the filter inlet pipe. The discharge of each is piped to the operating table, where there are cocks on the pipes to control the flow into a sink. These devices enable the operator to collect at each filter samples of the raw water on its way to the filter, the filtered water as it leaves the filter, or the dirty wash-water after it leaves the filter during the washing process. There are, also, at each operating table, sight tubes, the intended purpose of which is to show the character of the filtered water, the raw water, or the dirty wash-water, as the case may be. These devices for inspecting the filtered water and collecting samples of it have proved very helpful. The sight-tubes, however, as they now stand, have not proved very satisfactory, owing to the illumination being furnished by lamps which are not suitable. The intense brown appearance of the dirty wash-water, due to the organic matter contained therein, makes it improbable that the sight-tubes will ever be of much assistance in this plant in determining when the application of wash-water should cease. This can be found much better by an inspection of the water in the filter tank itself, which is illuminated by an electric light favorably situated.

Plates XXXVII and XXXVIII show the general arrangement of the filter-house and the marble operating tables placed opposite each filter.

Description and Results of Operation.

In brief terms, the general procedure of operating a mechanical filter plant of this character may be said to consist of the preparation of solutions of coagulating chemical, the application of the same to the river water in quantities adapted to its character, the cleaning of the filters from time to time when the clogging materials in the sand layers exhaust the available head, and the adjustment of the number of filters in service to yield the quantity of filtered water corresponding to the demands made upon the clear-water basin by the main pumping station.

With a plant equipped with such automatic devices as are provided at these works the operation of the filters themselves is a simple matter, and can be entrusted to ordinary intelligent laborers, subject to the oversight of a foreman. The preparation and application of solutions of coagulant require somewhat more attention, and, to be done effectively, and at the same time economically, there is required the attention of an intelligent and watchful superintendent capable of taking advantage of a certain amount of analytical evidence showing from time to time the character of the water which he has to treat. There are, of course, some other matters occasionally requiring attention, such as the cleaning of the coagulating basin, the packing of valves, and other work incidental to such a system of piping and mechanical appliances.

These filtration works, as already stated, have been in continuous service since September 4th, 1902. During the first year of service this plant is being operated under the general oversight of the writer, and during the first six months it has been under the immediate charge of Mr. George A. Johnson.

The object of conducting a series of careful investigations of the plant during its initial year of service is to obtain information whereby the plant can be operated to best advantage in the treatment of the local water as it passes through its various seasonal changes, and especially to ascertain the most judicious manner of coagulating the water and of washing the filters, and to prepare schedules whereby the regular attendants may operate the plant properly, at a later date.

As already stated, the filter tanks in the south wing have not yet been charged with sand, and among the special studies undertaken is that of the determination of the size of sand best adapted to local conditions. These and other matters led to establishing at the outset a schedule which involved the determination of data upon several points of importance.

Differential Tests.—Twelve of the sixteen filters in the north wing have been used regularly for obtaining data for differential or comparative purposes. They consist of six pairs, in duplicate. One pair contains the normal sand as originally specified, another coarse sand, another fine sand, another normal sand operated at a high rate, and another normal sand operated at a low rate. The final pair contains normal sand in which no air is used in cleaning the sand layers. Wash-

water and air are applied in the same manner to the five pairs of filters first mentioned. Unless otherwise stated, the rate of filtration is normal, 125 000 000 galls. per acre daily, or about 2 galls. per square foot per minute. The remaining filters in the north wing, when in service, are used for studying the best rate of application of wash-water and of air, and of other allied matters which can be taken up as individual studies.

The essential details of the twelve filters used for differential purposes are indicated in Table No. 2.

TABLE NO. 2.—SUMMARY OF THE ESSENTIAL DETAILS OF FILTERS.

Filter number.	Sand Layer.			Air used in washing.	Rate of Filtration.	
	Grade.	Effective size. Millimeters.	Uniformity coefficient.		Millions of gallons per acre daily.	Approximate gallons per square foot per minute.
1.....	Coarse.	0.44	1.32	Yes.	125	2
12.....	Coarse.	0.46	1.50	Yes.	125	2
3.	Fine.	0.37	1.38	Yes.	125	2
7.....	Fine.	0.35	1.51	Yes.	125	2
2.....	Normal.	0.40	1.50	Yes.	125	2
8.....	Normal.	0.42	1.43	Yes.	125	2
13.....	Normal.	0.39	1.50	No.	125	2
16.....	Normal.	0.38	1.50	No.	125	2
9.....	Normal.	0.40	1.42	Yes.	80	1.25
10.....	Normal.	0.41	1.46	Yes.	80	1.25
4.....	Normal.	0.41	1.44	Yes.	185	3
6.....	Normal.	0.41	1.44	Yes.	185	3

Force Employed.—Owing to the amount of work involved by the special tests, together with all other special studies indicated herein, the force employed in the operation of these works, up to the present time, has been considerably in excess of that which will suffice later. It is also to be borne in mind that at the outset the attendants employed for the operation of this plant were entirely unfamiliar with the operation of mechanical filters, and that there has been necessary a period of instruction during which it was important not to require of the men more detailed observations than they could readily make. Thus far, Mr. Johnson has been assisted by nine men, three of whom were technically trained. Of the latter, one devoted himself exclusively to engineering matters and the compilation of results, one to analytical work, and the third to general work both in the laboratory and in operating the plant. There is one filter attendant on each

watch of twelve hours, and one man in the machinery-room. There is also one mechanic on duty during the day, and one boy, as general helper in the laboratory and as janitor.

When the plant is operating at full capacity in the future, it is expected that there will be two trained men, say, a superintendent and an assistant superintendent, both of whom will be familiar with ordinary analytical matters, and two filter attendants and one attendant in the machinery-room, on each watch. Besides these there will be a janitor or laboratory helper. At times there will be required some service by a mechanic, in connection with the machinery, but it is expected that this can be attended to by the mechanics employed at the pumping station nearby. Assuming that there will be required the service of a mechanic equal to continuous labor of one man per day, the total force employed, with 12-hour shifts, would be ten men, including the man in charge and his principal assistant.

Observations and Analyses Made.—A close watch has been kept upon all principal features connected with the operation of these works. Hourly readings of the levels of the water in the coagulating basin and clear-water basin, and in the coagulant solution tanks are taken and recorded, as well as of the loss of head as indicated by the gauges on each filter in service. Careful records are also made of all observations connected with the washing of filters, enabling a continuous and complete record to be maintained for each filter, as to the periods between washings, the quantity of water filtered and the amount of wash-water and air applied.

Regarding analytical work, samples of the river water and the effluents of the coagulating basin and the clear-water basin are collected three times a day, to be examined for numbers of bacteria, amount of turbidity, color, amorphous matter and alkalinity. The water before and after filtration is also examined for color and turbidity at 2-hour intervals. At least once each day, a sample from the effluent of each individual filter in service is examined bacterially. From time to time samples of the filtered water from each filter in turn have been collected at frequent intervals, to show the uniformity in composition of the filtered water. At frequent intervals most careful tests have also been made regarding the presence of coagulant in the filtered water. Once a week, as a rule, chemical analyses of the raw and filtered water have been made. In addition to

this, many special observations have been made, in order to throw light upon such matters as the best manner of washing the filters, judged by the rate at which the clogged materials were removed from the sand layer, as shown by the character of the dirty wash-water. Frequent analyses of the sand layers have also been made, not only for their contents as to bacteria and suspended matters, but also to show their uniformity in size as indicated by mechanical analyses.

Up to February 1st, the amount of analytical work performed is indicated by Table No. 3.

TABLE No. 3.—SUMMARY OF ANALYTICAL WORK.

Complete chemical analyses	30
Partial analyses, for alkalinity, alumina, color and turbidity	5 120
Other special analyses, including specific gravity of coagulant solution	340
Complete microscopical examinations	16
Partial examinations for amorphous matter	148
Examination for numbers of bacteria	4 260
Mechanical analyses of filtering material	545

Record of Results.—A record of the principal results obtained is given in Tables Nos. 4 and 5.

Table No. 4 is a summary of the leading results by days, including the amount of coagulant applied, the percentage of wash-water, and the alkalinity, turbidity, color, amorphous matter and bacteria in the river water, the effluent of the coagulating basin and the effluent of the filters.

Table No. 5 shows the results of the chemical analyses of the raw and filtered water.

The number of microscopical organisms in the river water has ranged from 20 to 200 per cubic centimeter.

Coagulant.—Sulphate of alumina is the coagulant which has been used regularly thus far. Arrangements have been made for the application of copperas and lime, with the view to seeing if such treatment is applicable for purposes of coagulation under the existing local conditions, and, if so, to ascertain the cost, as compared with sulphate of alumina.

Solutions of sulphate of alumina have usually been prepared of 2% strength. When the full plant is in operation stronger solutions will be used. The diluter solutions are now used for purposes of securing a better control in the rate of application with the devices in hand.

The sulphate of alumina is obtained from the Pennsylvania Salt Manufacturing Company, and costs about 1 cent per pound. It contains no free sulphuric acid, practically no sediment, and about 17% of water-soluble aluminum oxide, with traces of iron.

Up to February 1st, the quantity of sulphate of alumina applied to the river water averaged 1.30 grains per gallon. Computed from the filtered water, the quantity was 1.35 grains per gallon. The range in quantity applied was from 0.29 to 2.17 grains, depending principally upon the amount of color and amorphous matter contained in the raw river water. Some evidence of the relation between the required amount of coagulant and the removal of color, bacteria, etc., under different conditions is indicated further on.

Soda.—The alkalinity of the river water became low, as compared with that necessary for the decomposition of the sulphate of alumina required for the treatment of the freshet water, during the latter half of December, and from December 17th to 30th, inclusive, there was applied a solution of soda ash, ranging in quantity from 0.16 to 0.63, and averaging 0.49 grain per gallon. During this period there were numerous occasions when the composition of the river water changed quite rapidly, and for this reason it was considered wise to apply soda in somewhat larger quantities and for a somewhat longer period than would appear to be called for by an inspection of the data in Table No. 4. On these occasions it was imperative that analyses of the river water be made from time to time throughout the entire 24 hours. It was the endeavor to apply soda so that the final filtered water would at all times contain at least 5 parts per million of alkalinity, capable of decomposing more than ½ grain of sulphate of alumina per gallon.

Efficiency of Coagulating Basin.—In Table No. 6 is given a monthly summary of the principal constituents of the river water before and after it passed through the coagulating basin. The average period of coagulation is also noted.

TABLE No. 4—(*Continued*). DAILY SUMMARY OF LEADING AVERAGE RESULTS OF OPERATION.

Day, Oct., 1902.	Period between washings. Hours.	Percentage of wash-water.	Sulphate of alumina. Grains per gallon.	Parts per Million.								Per Cubic Centimeter.				
				Alkalinity.		Turbidity.			Color.			Amorphous matter.		Bacteria.		
				River water.	Filt. water.	River water.	Subs. water.	Filt. water.	River water.	Subs. water.	Filt. water.	River water.	Subs. water.	River water.	Subs. water.	Filt. water.
1	9.37	4.1	1.76	18	9	12	8	0	50	30	7	3 500	620	11 000	350	60
2	8.36	4.2	1.67	16	7	10	7	0	48	31	6	2 000	600	2 800	170	28
3	8.31	4.1	1.22	19	9	9	7	0	48	19	12	1 100	600	2 100	250	75
4	6.65	5.4	1.19	19	12	9	5	2	50	33	27	1 050	400	1 000	290	275
5	6.10	5.9	1.49	19	11	8	6	2	50	32	19	1 200	800	2 700	325	65
6	6.97	4.9	1.55	20	8	8	7	0	50	29	8	1 500	300	2 700	325	28
7	7.02	4.3	1.40	19	10	8	6	0	51	27	7	800	200	1 200	650	80
8	6.57	5.3	1.36	21	10	8	6	0	52	28	8	800	290	750	700	24
9	5.84	5.9	1.36	20	11	7	5	1	51	27	9	1 500	600	2 300	425	160
10	6.17	5.4	1.44	22	12	6	5	1	58	35	12	1 500	500	2 300	1 100	290
11	6.68	5.5	2.01	22	13	5	4	1	59	36	9	500	200	6 800	950	220
12	5.76	6.0	1.65	18	11	4	3	0	51	30	4	.....	.....	14 000	1 300	300
13	8.03	4.3	1.46	17	9	5	4	1	56	37	5	300	100	3 700	1 000	160
14	6.64	5.9	1.31	23	12	5	4	1	55	37	10	1 000	300	6 900	450	170
15	7.51	4.5	1.79	24	10	5	5	1	57	27	6	1 200	500	600	160	19
16	8.13	4.3	1.93	23	10	5	4	1	57	28	3	1 500	500	325	200	11
17	8.85	3.8	2.17	23	7	4	3	1	54	33	3	1 000	400	500	130	12
18	8.23	4.1	1.95	27	7	3	3	1	51	29	3	800	200	600	100	16
19	8.81	4.8	1.65	26	11	3	3	2	53	30	2	700	400	300	120	15
20	6.20	6.0	1.63	26	14	3	3	2	52	33	5	1 000	200	275	120	25
21	8.50	4.5	1.61	29	12	3	3	2	53	34	6	1 500	400	300	140	50
22	7.02	5.5	1.65	26	13	4	5	1	53	36	6	1 200	400	700	350	48
23	7.19	5.1	1.66	27	14	5	3	1	53	32	6	1 000	400	1 000	450	36
24	7.40	5.4	1.65	30	16	3	4	1	54	38	4	1 200	400	1 000	600	60
25	9.85	3.6	1.73	32	18	4	4	1	53	35	3	1 000	300	3 100	475	80
26	8.83	3.8	1.52	36	20	4	4	2	49	29	3	1 200	350	1 600	900	150
27	8.61	3.8	1.45	32	20	3	3	2	49	26	2	800	290	3 900	1 000	100
28	8.36	4.4	1.54	28	15	7	5	2	42	38	2	800	300	18 300	3 200	110
29	11.39	3.3	1.45	18	8	7	6	1	51	34	4	900	300	13 600	1 100	100
30	10.27	3.8	1.61	18	9	5	5	1	51	29	4	700	280	7 200	1 500	95
31	8.12	4.5	1.52	17	7	7	7	1	50	22	4	600	180	3 500	1 400	34
Averages	7.79	4.8	1.59	23	12	6	5	1	52	31	7	1 100	380	3 800	650	90

TABLE No. 4. Daily Summary of Leading Average Results of Operation.

Day, Sept., 1902.	Period beween washings. Hours.	Percentage of wash-water.	Sulphate of alumina. Grains per gallon.	Parts per Million.								Per Cubic Centimeter.				
				Alkalinity.		Turbidity.			Color.			Amorphous matter.		Bacteria.		
				River water.	Filt. water.	River water.	Subs. water.	Filt. water.	River. water.	Subs. water.	Filt. water.	River water	Subs. water.	River water.	Subs. water.	Filt. water.
4	6.61	5.3	1.31	51	41	7	..	3	28	..	6	.....	.....	1 100	.....	200
5	10.12	3.8	0.64	50	44	8	..	2	30	..	8	.....	.....	1 500	.....	150
6	10.55	3.5	0.39	51	44	8	..	3	32	..	10	.....	.....	2 000	.....	150
7	11.49	2.9	0.32	48	46	8	5	5	29	15	15	.....	.....	2 000	1 300	200
8	14.52	2.4	0.35	48	46	9	4	5	29	21	15	.....	.....	400	.....	210
9	10.13	3.3	0.29	56	46	9	4	5	29	20	16	.....	.....	4 000	1 100	400
10	8.23	4.2	0.75	54	48	11	5	2	28	10	7	.....	.....	1 000	500	350
11	7.65	4.4	0.68	46	40	10	5	2	28	10	8	.....	.....	1 400	425	170
12	8.47	4.0	0.52	44	39	9	5	2	25	10	8	.....	.....	1 600	500	170
13	8.90	3.9	0.62	39	34	8	4	2	25	18	15	.....	.....	1 900	400	170
14	8.68	4.2	0.64	39	35	8	4	2	24	..	10	.....	.....	.....	.....	....
15	8.00	4.3	0.67	40	35	9	4	2	23	15	10	.....	.....	1 800	500	160
16	7.98	4.2	0.65	41	36	9	5	2	23	16	7	.....	.....	850	475	110
17	8.01	3.9	0.72	45	40	7	3	2	28	15	8	.....	.....	700	350	170
18	8.12	4.1	0.74	44	39	9	5	2	28	18	8	.....	.....	1 500	1 000	150
19	9.00	3.7	0.78	43	38	9	5	2	28	28	4	.....	.....	2 500	400	210
20	8.10	4.0	0.70	44	38	8	4	2	31	20	7	.....	.....	1 700	250	150
21	7.67	4.3	0.83	45	39	8	6	2	36	22	9	.....	.....	1 500	375	120
22	8.52	3.9	0.89	47	40	11	..	2	45	24	6	.....	.....	1 000	750	325
23	7.03	4.9	0.79	47	41	7	4	2	22	13	6	.....	.....	400	250	80
24	7.71	4.5	0.83	47	42	7	4	2	26	19	6	.....	.....	400	110	30
25	7.23	4.9	0.81	49	42	8	3	2	25	18	7	.....	.....	700	65	60
26	6.82	5.2	0.74	48	39	11	7	3	24	23	11	.....	.....	.....	.....	....
27	6.35	6.8	0.75	28	23	20	14	5	38	25	25	.....	.....	.....	.....	....
28	7.42	5.0	1.19	17	12	15	10	4	35	32	24	.....	.....	3 600	2 000	300
29	7.89	4.6	1.24	16	9	18	11	3	54	32	21	2 800	.....	12 000	8 000	400
30	7.22	5.1	1.31	19	9	15	8	3	52	34	22	2 400	.....	80 000	59 000	220
Averages	8.46	4.3	0.74	42	36	10	6	3	31	20	11	.....	.....	5 400	3 900	190

The quantity of amorphous matter is expressed in standard units, according to Whipple's method. Standard nutrient gelatine, reaction 1½% acid, is used in determining the numbers of bacteria, the period of cultivation being 48 hours, at 20° Cent.

TABLE No. 4 —(*Continued*). DAILY SUMMARY OF LEADING AVERAGE RESULTS OF OPERATION.

Day, Dec., 1902.	Period between washings. Hours.	Percentage of wash-water.	Sulphate of alumina. Grains per gallon.	Parts per Million.								Per Cubic Centimeter.				
				Alkalinity.		Turbidity.			Color.			Amorphous matter.		Bacteria.		
				River water.	Filt. water.	River water.	Subs. water.	Filt. water.	River water.	Subs. water.	Filt. water.	River water.	Subs. water.	River water.	Subs. water.	Filt. water.
1	13.18	3.2	1.70	32	19	4	3	1	47	33	5	120	50	5 500	2 300	75
2	11.60	3.5	1 59	32	18	3	3	1	43	32	6	130	70	4 800	1 900	40
3	14.91	2.9	1.72	30	17	5	3	2	46	29	4	110	40	8 900	2 400	50
4	10.84	3.8	1.61	28	16	4	1	1	46	29	5	110	40	9 200	3 000	40
5	12.11	3.5	1.82	26	13	5	3	1	48	31	6	130	50	13 000	3 300	35
6	11.52	3.7	1.48	25	13	5	3	1	53	37	6	250	70	10 100	2 500	75
7	10.22	4.2	1.75	25	12	4	3	0	45	30	6	350	90	9 800	1 700	55
8	10.89	3.8	1.73	25	13	4	2	1	48	23	6	300	150	9 200	3 200	140
9	9.38	4.5	1.53	25	13	3	2	1	47	27	4	280	100	7 200	3 300	375
10	10.94	3.8	1.73	27	13	3	2	0	51	21	6	240	110	5 300	2 100	100
11	8.54	4.5	1.70	28	14	3	1	1	47	20	6	160	80	3 400	1 100	33
12	12.36	3.2	1.75	28	16	3	2	0	37	18	5	150	70	2 800	1 100	30
13	8.78	4.5	2.01	28	17	2	1	1	41	29	6	130	70	2 800	600	29
14	9.80	4.1	1.68	29	17	2	1	1	35	18	6	190	100	2 100	500	25
15	11.09	3.6	1.72	28	17	2	1	1	34	18	5	250	130	3 700	400	25
16	7.75	5.2	1.83	23	14	6	4	1	42	18	5	230	130	6 600	1 100	32
17	5.91	7.4	1.85	10	7	10	5	1	49	19	4	1 700	500	10 100	500	60
18	9.09	4.5	2.00	10	6	14	8	2	44	24	5	800	400	9 200	2 200	60
19	8.29	4.7	1.79	10	7	13	8	2	51	25	6	600	300	8 900	4 800	70
20	8.77	4.4	1.76	11	7	16	11	1	42	21	4	300	160	9 900	2 500	45
21	9.27	4.5	1.93	12	7	11	7	0	41	23	4	1 000	500	4 400	1 700	18
22	8.16	4.9	1.82	9	6	19	15	1	48	25	4	1 200	450	5 800	1 700	27
23	8.23	4.9	1.84	8	5	19	8	1	43	21	3	1 100	550	3 200	1 600	25
24	10.38	4.1	1.72	10	6	12	6	1	38	21	5	900	500	6 800	2 300	39
25	10.24	3.9	1.73	11	8	7	5	0	49	22	4	800	390	4 000	1 400	35
26	10.51	3.8	1.77	12	8	9	7	1	45	20	5	600	320	4 200	1 200	36
27	9.98	3.9	1.37	14	12	7	4	0	45	20	4	500	280	3 600	1 700	28
28	9.55	4.0	1.49	15	10	9	4	0	41	23	4	410	250	3 600	1 000	14
29	9.13	4.1	1.46	17	9	9	4	1	43	25	4	310	180	6 700	850	11
30	9.56	4.0	1.49	18	8	4	3	0	32	22	4	250	130	2 300	800	7
31	9.43	4.1	1.35	18	9	3	2	1	28	18	5	200	100	1 700	800	6
Averages	10.02	4.2	1.70	23	12	7	4	1	44	24	5	450	210	5 800	1 800	50

TABLE No. 4.—(*Continued.*) DAILY SUMMARY OF LEADING AVERAGE RESULTS OF OPERATION.

Day, Nov., 1902.	Period between washings. Hours.	Percentage of wash-water.	Sulphate of alumina. Grains per gallon.	PARTS PER MILLION.								PER CUBIC CENTIMETER.				
				Alkalinity.		Turbidity.			Color.			Amorphous matter.		Bacteria.		
				River water.	Filt. water.	River water.	Subs. water.	Filt. water.	River water.	Subs. water.	Filt. water.	River water.	Subs. water.	River water.	Subs. water.	Filt. water.
1	7.41	5.0	1.05	19	14	4	4	3	51	45	28	800	290	1 700	1 300	210
2	3.93	10.8	1.63	20	13	6	6	3	47	34	14	700	220	1 300	500	70
3	7.93	5.4	1.55	21	11	3	3	2	49	24	4	400	140	1 200	225	19
4	7.62	5.3	1.57	22	11	4	3	2	50	33	5	300	90	1 300	350	24
5	6.99	6.0	1.70	24	11	5	4	2	51	39	6	210	60	1 200	400	48
6	7.47	5.4	1.76	25	13	5	4	1	52	28	6	400	95	1 800	550	12
7	7.44	5.7	1.81	26	16	6	4	1	49	28	6	500	100	2 400	550	11
8	8.13	4.8	1.44	26	18	6	4	2	47	16	7	280	80	3 100	550	33
9	7.81	5.5	1.94	27	15	5	3	2	44	25	5	340	90	2 800	550	60
10	4.54	10.9	1.75	27	15	5	3	1	47	38	5	120	35	1 900	375	45
11	9.12	4.8	1.80	29	22	5	3	2	47	33	20	310	75	3 100	425	15
12	11.97	3.4	1.79	29	18	5	3	1	49	33	4	190	50	1 400	475	16
13	10.12	4.0	1.71	29	18	5	3	3	45	24	5	150	40	1 800	500	22
14	12.29	3.3	1.60	32	21	5	4	2	46	30	5	110	40	2 600	800	27
15	10.09	3.8	1.65	33	20	5	3	2	49	31	4	400	95	1 700	1 000	25
16	10.75	4.0	1.64	32	21	6	5	3	45	29	4	300	85	2 900	650	25
17	11.81	3.7	1.47	32	22	7	5	2	41	28	4	350	100	1 900	600	23
18	10.84	3.7	1.56	35	22	6	4	2	39	26	5	200	55	1 500	900	22
19	10.68	4.3	1.77	35	22	5	5	3	38	27	4	170	40	1 300	450	11
20	10.64	3.8	1.64	36	24	5	5	3	39	28	8	150	40	1 400	475	19
21	10.88	3.8	1.75	36	24	5	5	2	42	23	4	230	50	2 300	500	7
22	11.70	3.5	1.78	35	24	6	5	1	41	24	3	200	50	4 200	850	37
23	11.50	3.5	1.58	36	25	3	3	2	43	26	4	150	60	7 000	1 800	42
24	11.14	3.8	1.60	35	24	4	4	1	44	27	3	180	40	5 000	2 100	170
25	10.14	3.9	1.35	35	25	3	3	1	44	27	5	250	50	8 000	5 000	90
26	8.56	4.8	1.41	35	26	3	3	1	38	30	5	280	70	5 200	2 200	325
27	8.09	5.4	1.31	34	23	3	3	1	48	24	6	300	80	6 700	2 900	180
28	11.46	3.7	1.57	34	22	4	4	2	49	24	5	180	40	9 800	3 600	100
29	10.29	4.1	1.89	33	19	5	5	1	47	36	6	120	50	11 600	2 300	100
30	12.79	3.4	1.73	32	17	5	5	2	45	32	7	100	30	5 400	1 500	20
Averages	9.46	4.8	1.63	30	19	5	4	2	45	28	7	280	80	3 500	1 100	60

TABLE No. 4 —(*Concluded*). DAILY SUMMARY OF LEADING AVERAGE RESULTS OF OPERATION.

Day, Jan., 1903.	Period between washings. Hours.	Percentage of wash-water.	Sulphate of alumina. Grains per gallon.	Parts per Million.									Per Cubic Centimeter.				
				Alkalinity.		Turbidity.			Color.				Amorphous matter.		Bacteria.		
				River water.	Filt. water.	River water.	Subs. water.	Filt. water.	River water.	Subs. water.	Filt. water.		River water.	Subs. water.	River water.	Subs. water.	Filt. water.
1	10.82	3.6	1.05	20	11	2	2	0	39	20	4		220	100	1 700	750	12
2	13.09	3.1	0.93	21	13	3	2	0	28	18	3		180	75	1 500	1 200	21
3	10.03	4.0	1.12	19	12	4	3	0	25	18	4		100	50	3 300	1 600	12
4	10.33	3.8	1.03	16	9	3	2	0	25	17	6		90	40	4 400	2 600	17
5	12.81	3.1	0.90	16	9	4	3	1	28	18	5		100	50	4 400	2 600	80
6	11.62	3.3	0.68	16	10	5	3	0	37	21	5		80	40	3 700	1 800	140
7	13.41	2.9	0.57	17	11	4	3	0	35	24	10		140	110	2 400	2 000	400
8	10.54	3.6	0.68	17	12	3	2	0	32	26	5		130	70	1 600	1 200	275
9	13.11	3.0	0.64	18	13	3	1	1	32	19	6		120	80	1 200	850	65
10	11.79	3.2	0.67	19	14	2	1	0	29	22	6		140	90	2 200	210	55
11	12.40	3.0	0.66	20	16	1	2	0	29	19	6		160	70	650	190	110
12	13.52	2.9	0.66	21	16	5	3	1	28	20	4		190	110	2 100	900	150
13	9.71	4.2	0.76	24	18	4	3	1	27	22	6		150	190	1 600	500	160
14	12.79	3.0	0.61	24	20	4	2	0	28	18	6		120	70	1 400	1 200	190
15	12.81	2.9	0.69	24	19	4	3	0	28	20	6		110	75	1 500	1 300	70
16	12.75	3.0	0.80	24	18	3	2	0	26	19	5		130	80	1 800	650	80
17	15.90	2.3	0.73	25	20	4	2	0	23	17	5		150	90	2 300	1 400	100
18	18.08	2.2	0.68	25	20	3	3	0	22	16	5		150	75	4 200	1 000	130
19	16.55	2.2	0.65	27	22	3	3	0	22	17	4		140	80	4 000	2 600	190
20	15.38	2.4	0.56	28	24	3	2	0	23	17	5		120	60	5 200	1 200	300
21	12.79	3.0	0.71	22	19	20	17	0	31	24	6		120	70	6 000	2 300	225
22	10.54	3.7	1.03	16	9	23	11	0	35	25	6		700	400	5 600	1 700	120
23	12.64	3.0	0.92	15	8	14	9	0	36	25	5		500	300	4 300	950	80
24	11.80	2.9	0.94	16	9	12	8	0	36	23	5		400	250	8 900	3 000	150
25	14.93	2.3	0.98	17	10	13	12	0	49	32	5		300	160	11 200	3 200	140
26	11.26	3.3	1.06	18	10	12	10	0	46	27	5		210	100	9 400	3 200	85
27	14.02	2.5	1.27	20	11	11	7	0	42	26	5		180	90	6 700	2 900	40
28	12.58	2.9	1.35	21	11	10	6	0	43	26	5		300	180	4 700	1 600	45
29	11.02	3.0	1.24	19	10	9	5	0	35	20	5		280	150	5 800	1 100	22
30	10.80	3.1	1.08	18	11	8	5	0	30	17	4		250	130	4 500	1 800	34
31	12.87	2.3	0.80	16	10	9	7	0	30	20	5		280	150	5 200	3 900	65
Averages	12.67	3.0	0.84	20	14	6	5	0	31	21	5		200	115	4 000	1 700	110

TABLE No. 5.—Results of Chemical Analyses of River Water and Filtered Water.

(Parts per Million.)

Collected.		Source. R = River water. F = Filtered water.	Temperature, in degrees Centigrade.	Silica turbidity.	Color, Plat. standard.	Oxygen consumed.	Nitrogen as:						Chlorine.	Sulphuric acid.	Incrusting constituents.	Alkalinity.	Total hardness.	Residue on Evaporation.			Iron.	Carbonic acid (free and half-bound).
							Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.										
Date, 1902.	Hour.						Total.	Suspended.	Dissolved.									Total.	Suspended.	Dissolved.		
Oct. 16	12 M.	R	12	4	58	7.6	0.212	0.069	0.143	0.033	0.004	0.012	2.0	3	4	22	26	77	7	70	0.5	....
Oct. 16	12 M.	F	12	1	3	1.2	0.074	.....	.....	0.024	0.000	0.080	2.0	11	16	10	26	70	....	....	0.0	....
Oct. 22	12 M.	R	12	4	55	7.6	0.191	0.014	0.177	0.036	0.003	0.013	3.0	3	3	24	27	71	2	69	0.4	10
Oct. 22	12 M.	F	12	0	5	2.1	0.110	.....	.....	0.027	0.000	0.087	3.0	14	14	11	25	69	....	....	0.2	8
Oct. 29	9 A. M.	R	13	5	51	8.7	0.216	0.031	0.185	0.025	0.003	0.020	4.0	3	3	18	21	69	10	59	0.8	8
Oct. 29	9 A. M.	F	14	1	6	2.0	0.143	.....	.....	0.021	0.001	0.093	4.0	9	10	10	20	65	....	....	0.1	13
Nov. 5	9 A. M.	R	10	5	50	7.2	0.205	0.006	0.199	0.025	0.003	0.060	4.0	1	1	25	26	73	7	66	0.4	9
Nov. 5	9 A. M.	F	10	1	3	1.7	0.160	.....	.....	0.009	0.000	0.110	3.8	10	8	12	20	69	....	....	0.0	11
Nov. 26	10 A. M.	R	8	3	43	....	.....	.....	.....	.....	0.002	0.105	3.2	....	0	31	31	73	2	71	0.3	12
Nov. 26	10 A. M.	F	9	2	5	....	.....	.....	.....	.....	0.004	0.105	3.2	....	4	27	31	75	....	....	0.1	15
Dec. 4	11 A. M.	R	6	4	45	....	.....	.....	.....	.....	0.003	0.080	3.5	....	20	28	48	70	2	68	0.2	14
Dec. 4	11 A. M.	F	7	1	7	....	.....	.....	.....	.....	0.063	0.085	3.5	....	21	17	48	65	....	....	0.0	14
Dec. 10	2 P. M.	R	5	3	51	....	.....	.....	.....	.....	0.003	0.170	3.5	....	18	26	44	79	2	77	0.2	8
Dec. 10	2 P. M.	F	5	1	6	....	.....	.....	.....	.....	0.003	0.220	3.5	....	31	13	44	75	....	....	0.0	10
Dec. 17	10 A. M.	R	3	75	70	7.1	0.135	0.060	0.075	0.033	0.004	0.095	2.5	3	7	10	17	88	23	65	0.3	10
Dec. 17	10 A. M.	F	3	1	4	1.2	0.039	.....	.....	0.018	0.001	0.160	2.5	22	....	9	....	56	....	....	0.0	16
Dec. 24	12 M.	R	3	9	40	5.1	0.019	0.003	0.016	0.008	0.000	0.080	2.0	3	7	25	32	58	7	51	0.2	6
Dec. 24	12 M.	F	3	0	2	1.1	0.015	.....	.....	0.008	0.000	0.085	1.7	13	9	16	25	49	....	....	0.0	11
Dec. 31	11 A. M.	R	2	4	30	4.7	0.014	0.001	0.013	0.007	0.000	0.160	1.7	3	14	19	33	66	6	60	0.1	6
Dec. 31, 1903.	11 A. M.	F	2	0	5	1.0	0.011	.....	.....	0.006	0.000	0.160	1.7	17	26	9	35	60	....	....	0.0	11
Jan. 8	10 A. M.	R	5	5	30	3.8	0.012	0.001	0.011	0.002	0.002	0.210	3.0	4	8	17	25	59	7	52	0.2	10
Jan. 8	10 A. M.	F	4	0	2	1.3	0.008	.....	.....	0.002	0.002	0.210	2.8	7	12	12	24	72	....	....	0.0	12
Jan. 14	1 P. M.	R	4	4	26	5.1	0.014	0.002	0.012	0.001	0.001	0.150	3.0	3	7	24	31	64	5	59	0.2	12
Jan. 14	1 P. M.	F	4	0	9	2.0	0.010	.....	.....	0.001	0.001	0.150	3.0	7	10	20	36	70	....	....	0.0	14
Jan. 21	12 M.	R	3	20	28	4.2	0.016	0.002	0.014	0.008	0.003	0.060	4.0	2	3	28	31	70	10	60	0.2	7
Jan. 21	12 M.	F	4	0	6	2.0	0.011	.....	.....	0.006	0.003	0.060	4.2	6	7	24	31	61	....	....	0.0	6
Jan. 28	11 A. M.	R	4	10	40	4.6	0.014	0.002	0.012	0.004	0.004	0.250	3.0	4	5	21	26	59	7	52	0.3	9
Jan. 28	11 A. M.	F	4	0	5	1.8	0.007	.....	.....	0.005	0.004	0.250	3.0	12	13	11	24	51	....	...	0.0	12

On December 17th and 24th, the river-water sample was collected at a place before the application of soda reached the water.

The river water has a vegetable or musty odor, usually very slight: but, occasionally, during the autumn, it was quite pronounced. After filtration the odor in the water is somewhat less than in the river water.

The river water and filtered water contain, approximately, the same quantity of dissolved oxygen. In October the quantity was about 60% of that required for saturation. Since cold weather set in, the water has been nearly saturated with atmospheric oxygen, at times completely so.

Cleaning the Coagulating Basin.—The coagulating basin was first cleaned on November 10th, when there were about 8 ft. of accumulated sediment or sludge on the bottom. This was removed by draining and pumping out the sludge in the lower portion of the basin, river water being applied from time to time by opening the gates at the bottom of the stand-pipe at the north end. The sludge was liquid in its character, so that it formed apparently a layer of uniform thickness over the entire bottom, excepting perhaps over a limited area near the inlet.

TABLE No. 6.—Summary of Results Showing the Efficiency of the Coagulating Basin.

Month.	Period of coagulation and subsidence.	Turbidity.		Color.		Amorphous Matter.		Bacteria.	
		River water.	Coag. basin eff.	River water.	Coag. basin eff.	River water.	Coag. basin eff.	River water.	Coag. basin eff.
1902.	Hours.								
September.....	3.1	10	6	31	20	.....	.....	5 400	3 900
October.....	3.3	6	5	52	31	1 100	380	3 800	650
November.....	3.2	5	4	45	28	280	80	3 500	1 100
December.....	2.9	7	4	44	24	450	210	5 800	1 800
1903.									
January.....	2.8	6	5	31	21	200	115	4 000	1 700

On January 13th the coagulating basin was again cleaned out, and it was found that there was a layer of sediment about 5 ft. in thickness. The character of this sludge was examined more carefully than on the former occasion, and, from numerous samples, it was found to contain about 87% of water and 13% of dry solids. Of the latter, about 27% was found to be aluminum hydrate; the remainder consisted of the various matters removed from the river water.

There was some decomposition going on in the organic matter of the sludge, as removed, on both occasions, particularly in November, as indicated by the odors in the basin during cleaning. There was no sign, however, of such decomposition as might be classed as a septic action, and the sediment in no place had turned black, as has been noted in some instances, elsewhere.

Method of Washing the Filters.—Numerous studies have been made as to the best rate and pressure for the application of the wash-water,

and also the application of air for purposes of agitation, as well as the period during washing when air can be most advantageously applied. According to the evidence now available, the best procedure is to apply air at the commencement of the washing operation, under a pressure of 3 lbs., at a rate of about 20 to 25 galls. of free air per square foot of filtering surface per minute, and for a period of 3 minutes. At the commencement of the application of the air the water in the filter is drawn down to about 4 ins. above the sand layer, or 8 ins. below the overflow gutters. This is necessary, to prevent loss of sand. Next, there is applied filtered water under a pressure of about 25 ft., measured at the strainer system, at a rate of about 5½ galls. per square foot per minute, equal to about three-fourths of a vertical foot per minute, and continued until the wash-water, as it leaves the filters, is comparatively clean, and sufficiently so to enable the moving particles of sand at the surface of the layer to be readily seen. At this plant the wash-water clears in quite a well-defined manner, and, with a little practice, the attendants have no difficulty in determining when the end point is reached. As a rule, air has been applied a second time for about 1 minute during each washing, followed by the application of wash-water, to remove the air and to clean the sand to the same point as above described. During washing, the sand layer is raised about 3 ins., or to within 9 ins. of the top of the overflow gutter. The quantity of sand lost is very trifling. The average total time required for washing a filter is 12 minutes.

Percentage of Wash-Water Used.—The quantity of wash-water used is estimated from the duration of its application, and numerous observations have been made as to the rate of delivery of the wash-water pump, with the rheostat on the motor set at different points and for different levels of water in the clear-water basin, from which the wash-water pump takes its suction. Further, these measurements are checked repeatedly by noting the rate at which the water rises in the filter tanks and also in a measuring tank at the end of the sewer line into which the discharged wash-water is allowed to flow.

Up to February 1st, the average quantity of wash-water used for the entire plant was 4.2% of the water treated.

Comparisons of the quantity of wash-water required for the so-called normal filters, those of coarse and fine sand, and those operated at high and low rates, are contained in Table No. 7.

TABLE No. 7.—Comparison of the Quantity of Wash-Water Required in the Case of Filters Operated under Different Conditions.

(Averages for 20 weeks.)

Kind of sand.	Rate of filtration.	Percentage of wash-water required.
Normal	High	3.8
	Normal	4.1
	Low	4.4
Coarse	Normal	3.3
Fine	Normal	4.4

Period of Service.—The period of service of the filters, between washings, depends, of course, upon the character of the water as it reaches the sand layers, and, in general, may be said to bear an inverse relation to the percentage of wash-water. Up to February 1st, the total average period of service between washings of the filters was 9.68 hours. The ordinary range in length of runs of the filters has been from about 6 to 18 hours.

TABLE No. 8.—Summary of Results Showing the Effect of Air Agitation During the Process of Washing.

Month.	Normal Filters.		Filters without Air Agitation.	
	Average period of service. Hours.	Percentage of wash-water.	Average period of service. Hours.	Percentage of wash-water.
September	8.16	3.3	9.19	4.2
October	7.92	4.5	6.12	5.7
November	10.51	4.1	7.35	5.3
December	10.76	4.1	9.11	4.0
January	14.31	2.9	12.29	2.7

Effect of Air Agitation.—Filters Nos. 13 and 16, without exception, have been washed without the application of air. It is yet too soon to discuss comprehensively the value of the air, but an inspection of the sand layers of these two filters after washing shows that they contain sufficiently more clogging material than the regular filters to indicate that the air is of benefit. In November these filters gave shorter runs, and required more wash-water, than the so-called normal filters. An

inspection of all sand layers, at that time, with much detail, indicated that there was some fine sand accumulated in the upper quarter of an inch of the majority of the filters. This fine sand was scraped from the surface of each layer. Following that, these two filters, which received no air, became more normal in their operation, as regards the period of service and percentage of wash-water. The data thus far obtained upon this question are given in Table No. 8, showing the average length of service and percentage of wash-water for Nos. 2 and 8, normal filters, and for these special filters, Nos. 13 and 16.

Power Required.—The electric horse-power required for the operation of each of the various devices is indicated in Table No. 9.

TABLE No. 9.

ELECTRIC HORSE-POWER REQUIRED TO OPERATE THE VARIOUS DEVICES.

Motors to Operate.	Rated Horse-Power.
Wash-water pump	75
Blower	45
Chemical feed pump	2
Sludge pump	40
Soda pump	1
Main shafting	10
Effluent gate-valve	5

Removal of Bacteria.—The thoroughness with which the bacteria in the raw water are removed by these filtration works depends essentially upon the quantity of a coagulant applied.

Table No. 4 shows the evidence in the form of daily averages from the commencement of operations to date. By months, the bacterial results, together with the principal information related thereto, are shown in Table No. 10.

During each of the first three months there were quite a number of occasions when the bacteria in the filtered water were somewhat numerous; due, practically without exception, to interruptions in the proper rate of application of the coagulant. As has been stated already, this was due largely to obstruction in the suction of the pumps supplying the orifice tank, in most instances caused by splinters from the barrels containing the sulphate of alumina, and by foreign matters, such as leaves and shavings, getting into the mixing tanks. During this period, when the men were being trained in the operation of the plant,

there were several times when these interruptions were not detected until the coagulating basin had received a considerable quantity of river water insufficiently charged with coagulant. At the present time these matters have very little significance, owing to the familiarity with their work, on the part of the attendants, the use of more efficient screens to keep splinters and other matters from the suction of the pumps and the orifice tank, to the gong which is now rung by a float in the orifice tank whenever the solution becomes interrupted for a time equivalent to less than 1 minute's regular flow, and to the measuring cylinder upon the chemical feed pipe, enabling more accurate control to be made of the rate of application. During the month of December, it was the uniform intention to secure a high degree of bacterial efficiency from the filters, and this was done, with the exception that the samples obtained from the 8th to the 10th of December were affected by an interruption in the chemical feed.

TABLE No. 10.—Bacterial Results and Principal Information Relating Thereto.

(Averages by Months).

Month.	Sulphate of alumina. Grains per gallon.	Turbidity.			Color.			Amorphous Matter.		Bacteria.			
								Standard units per cubic centimeter.		Per cubic centimeter.			Percentage removal.
		River water.	Coag. basin effluent.	Filtered water.	River water.	Coag. basin effluent.	Filtered water.	River water.	Coag. basin effluent.	River water.	Coag. basin effluent.	Filt. water.	
1902.													
Sept.....	0.74	10	6	3	31	20	11	0	....	5 400	3 900	190	98.5
Oct.....	1.59	6	5	1	52	31	7	1 100	380	3 800	650	90	97.6
Nov.....	1.63	5	4	2	45	28	7	280	80	3 500	1 100	60	98.3
Dec.....	1.70	7	4	1	44	24	5	450	210	5 860	1 800	50	99.1
1903.													
Jan.....	0.84	6	5	0	31	21	5	200	115	4 000	1 700	110	97.2

During the month of January, lower quantities of coagulant were used intentionally, with the view to seeing the efficiency of different ratios, and, with the uniform rate of application of coagulant, the

bacterial results obtained during that month are of most value for this particular purpose.

Removal of Color.—It has been found, as a result of repeated examinations, especially in noting the appearance of the filtered water in a large porcelain-lined bath-tub, that it is not possible for a consumer to recognize any color when the filtered water contains 10 parts per million or less. A color of 20 parts is also practically unnoticeable to the consumer. These works have been operated with the view of keeping the color below 10 parts. It has been found, however, that the quantity of coagulant necessary to reduce it to that point is practically as great as that required to reduce it to 5 parts.

Table No. 11 shows the monthly average results of the applied coagulant, and the color in the raw and filtered water:

TABLE No. 11.—QUANTITIES OF COAGULANT APPLIED.
(Averages by Months.)

Month.	Sulphate of alumina. Grains per gallon.	Color.	
		River water.	Filtered water.
1902.			
September	0.74	31	11
October	1.59	52	7
November	1.63	45	7
December	1.70	44	5
1903.			
January	0.84	31	5

Special effort is being made to secure data from which may be deduced certain factors indicating the quantity of coagulant required for the proper treatment of the river water in its various conditions. It is yet too soon to discuss these factors.

Removal of Turbidity.—As noted by the record in Table No. 4, the turbidity of the filtered water usually ranges from nothing to 2 parts. Now and then it becomes as high as 3 parts. All these amounts may be properly recorded as traces, and it may be said that for all practical purposes the filtered water has no turbidity.

Removal of Organic Matter.—Based on the average results given in Table No. 5, the removal of organic matter by these filters is shown in Table No. 12.

TABLE No. 12.—Summary Showing the Removal of Organic Matter.

Parts per Million.				Percentage of Organic Matter Removed.	
Nitrogen as albuminoid ammonia.		Oxygen consumed.			
River water.	Filtered water.	River water.	Filtered water.	Albuminoid ammonia.	Oxygen consumed.
0.121	0.075	6.3	1.6	38	75

Removal of Tastes and Odors.—The Passaic River water ordinarily has a slightly musty or vegetable odor, and at times during the autumn it has a swampy odor which is noticeable to persons unfamiliar with the water, but which is not disagreeable, and, in fact, is hardly recognized by those familiar with surface waters from swampy areas. The removal of tastes and odors by filtration is appreciable, but when the swampy odor is present in the river water it is still clearly recognizable in the filtered water on careful examination. Studies of the practicability of removing it by aeration have been made, but it is found that this is unsuccessful, as the odors and tastes still persist after vigorous aeration for some 10 to 12 hours. The tastes and odors are evidently produced by oily substances liberated from the vegetable growths in the swampy areas, and, apparently, could be removed only by filtration through charcoal, by ozonization, or by intermittent filtration through sand at exceedingly low rates.

Removal of Coagulant.—In no case has the filtered water contained any undecomposed sulphate of alumina. Regarding the removal of the aluminum hydrate, ordinarily this is complete, although now and then the numerous analyses made indicate that faint traces of the hydrate in a very fine colloidal form have appeared in the filtered water. These traces are too small to be measured, although, in a general way, it may be said that there are times when it would probably amount to about 0.06 part per million, equal to 0.0035 grain per gallon. The average would be less than 0.01 part per million, corresponding to a removal of more than 99% of the hydrate contained in the raw water. These traces are gradually diminishing as the sand layers are becoming "ripened."

Change in Hardness.—Table No. 13 gives a comparison of the average hardness of the river and the filtered waters.

TABLE No. 13.—Comparative Hardness of the River and Filtered Waters.

Parts per Million.

River Water.			Filtered Water.		
Temporary. (Alkalinity.)	Permanent. (Incrusting constituents.)	Total hardness.	Temporary.	Permanent.	Total hardness.
23	12	35	15	19	34

Effective Size of Sand Grains.—The principal point in relation to the effective size of the sand grains is the importance of removing the fine particles contained in the sand. The specifications, as originally prepared, are none too severe. The effective size, within the range stated (see Table No. 1), and under the local conditions, makes no appreciable difference with regard to the quality of the filtered water, but the coarser sands allow a reduction in the percentage of wash-water used, as shown in Table No. 14.

TABLE No. 14.—Percentage of Wash-Water Required in Filters Containing Different Kinds of Sand Layers.

(Average for 20 weeks.)

Kind of sand.	Percentage of wash-water required.
Fine	4.4
Normal	4.1
Coarse	3.3

Effect of Rate of Filtration.—The rate of filtration, as far as the quality of the filtered water is concerned, does not seem to be a factor of significance. If the applied water is well coagulated, satisfactory results will follow with a rate of filtration at least as high as 185 000 000 galls. per acre per 24 hours, and with an inadequately coagulated water good results cannot be obtained at rates of 80 000 000 galls. per acre per 24 hours, or much less. That the number of bacteria in the filtered water is not materially affected by the rate of filtration is shown by Table No. 15.

TABLE No. 15.—Average Results, Showing Removal of Bacteria by Filters Operated at Different Rates.

(Averages for 20 weeks.)

Rate of filtration.	Rate of Filtration.		Bacteria per Cubic Centimeter.		Percentage of removal of bacteria.
	Gallons per acre daily.	Gallons per square foot per minute.	River water.	Filtered water.	
High	185 000 000	3.0	3 500	100	97.1
Normal	125 000 000	2.0	3 500	90	97.4
Low	80 000 000	1.2	3 500	80	97.7

The more recent results, obtained after the sand layers became ripened, show no appreciable differences.

Compared with the normal rate of 125 000 000 galls. the high and low rates affect the period of service and percentage of wash-water as shown in Table No. 16.

TABLE No. 16.—Average Results Showing the Effect of the Rate of Filtration on Period of Service and Percentage of Wash-Water.

(Average for 20 weeks.)

Rate of filtration.	Period of service. Hours.	Volume of water filtered per run.	Percentage of wash-water.
High	7.52	470 000	3.8
Normal	10.18	425 000	4.1
Low	12.93	358 000	4.4

The larger yield of filtered water between washings by the high-rate filters, apparently, is explained by the deeper penetration into the sand layers of matters removed from the water. Regarding the percentage of wash-water, the actual volume of water required per filter for cleaning does not seem to be exactly proportional to the amount of accumulated matters in the sand layer.

Regarding Costs.—It is not feasible, at the present time, to discuss questions of cost in as much detail as might be desired. However, information upon the principal items in the operation of the works is

contained in the foregoing pages, and the cost of construction per million gallons of nominal daily filtering capacity may be summarized as follows:

Coagulating basin and clear-water basin, including piping within the walls, and grading the grounds	$5 400
Supply and suction piping outside the structures	800
Filter tanks, including covers	1 500
Main building and wings, including floors, piers and entire superstructure, except the last item	2 000
Filter equipment, complete, including machinery within the buildings	4 800
Power equipment and outside wiring	800
	$15 300

Acknowledgment.—In closing, the writer desires to record his acknowledgments to J. Waldo Smith, M. Am. Soc. C. E., under whose direction these works were designed and built and are operated, for permission to make use of the data embodied in this paper.

DISCUSSION.

Mr. Hazen. ALLEN HAZEN, M. Am. Soc. C. E.—This paper is of unusual interest, as it represents a careful and scientific development of a method of filtration which has been used extensively in this country in a less perfected and developed form. This method is that commonly known as mechanical filtration, in distinction from the older type known as sand filtration, which has been used widely by European cities for many years, and more recently to a considerable extent in this country.

The water at Little Falls is free from excessive sediment, and is of a type for which sand filters would usually be considered preferable. For waters of the turbid type, particularly where the amount of sewage-polluting matter is not great, mechanical filters give better clarification than sand filters. Mechanical filters, because of their high rate of filtration, occupy less space and can be installed on sites which are not adequate for the construction of sand filters; and, apparently, it was for this reason that mechanical filters were selected in this case, although the removal of color, which is more complete in connection with the chemical treatment than is possible by sand filters unaided, was no doubt an important, although secondary, object reached by the selection.

As far as the clarification is concerned, there can be no question as to the treatment. The results secured, as shown by the records given by the author, are almost ideal. The point of greatest interest in connection with its operation is, whether it will remove the disease-producing properties with the same certainty that well constructed and operated sand filters do.

Most of our knowledge as to the improvement of the health of communities by filtering their water supplies relates to the changes effected by sand filters. Corresponding data for mechanical filters are as yet limited and unsatisfactory. The figures for bacterial efficiency given by the author promise much in this respect. It should be noted, however, that the raw water is much less polluted by sewage than the corresponding water in many places where sand filters have been used, as for example, at Poughkeepsie, Lawrence and Albany; and, as the author states, the death rates of the population supplied in the past with the water in its raw state have not been excessive. The test is thus a less searching one than would have been the case under other conditions, and, at the same time, the conditions left less room for doubt as to the outcome, from a sanitary standpoint, than would have been the case had the raw water been polluted by sewage to a much greater extent.

In a sand filter operating at a low rate of filtration, the removal of the disease-producing properties, which are, in general, the bacteria,

Mr. Hazen.

seems to depend upon the attraction of the bacteria for the sand, and for the matters which accumulate upon the sand grains in the course of filtration; and that action, as we know, is such that the removal of the bacteria is most complete. In a mechanical filter the rate of filtration is increased, in a general way, forty times. The result of this increase in rate is that the actions which make the sand filter efficient are no longer adequate to remove the bacteria, and the action of the filter becomes dependent upon the addition of coagulant to the water before filtration, and the formation of a flocculent precipitate in it which entangles the bacteria and allows them to be removed at the high rate. The efficiency of the filter, in this respect, depends absolutely upon the faithful and continuous application of coagulant. The problem reduces itself to devising mechanical means for securing at all times the application of the coagulant to the raw water in the right amount. If this can be accomplished thoroughly there can be no doubt as to the efficiency of the purification secured.

There are a great many mechanical filter plants in the United States. Unfortunately, most of them have failed in this respect at times. In some of them the failures have been so frequent and extended as to be habitual. Others have failed less frequently, but they have failed more frequently because the coagulant was not applied faithfully and continuously than from any other cause. In this plant a decided step has been taken in securing devices to insure the continuous application of the coagulant, as far as devices can be secured; for, after all, the human element is often the weakest link in the chain, and that cannot be eliminated altogether.

The probability of satisfactory operation is increased greatly by the laboratory which has been established in connection with the plant, where the operation is watched with care and in detail, and the results are recorded fully and impartially. This is a most important step in securing uniformly excellent results, and it is to be hoped that it will be followed in all important plants. The importance of such supervision is shown in the tables of results and by the fact, as noted by the author, that the lowest efficiencies obtained have followed the failure to secure perfect operation of the coagulating apparatus. Without the laboratory, these slight lapses would have passed unnoticed, and the improvements in the apparatus to correct them would not have been made.

A large part of our accurate knowledge of mechanical filtration has been derived from certain experiments made by the author at Louisville, Ky., and by the speaker at Pittsburg, Pa. In each case filters of what are known as the Warren and Jewell types, as well as certain other appliances, were installed. A comparison of some of the features of these earlier experimental filters with the Little Falls filters may be of interest. Some of the figures, necessarily, are only approximate.

Mr. Hazen.

TABLE No. 17.

	Little Falls filters.	Louisville Experimental Filters.		Pittsburg Experimental Filters.	
		Jewell.	Warren.	Jewell.	Warren.
Capacity of coagulating basin, in hours' supply, when rate of filtration is 125 000 000 galls. per acre daily	1.28	0.48	1.15	0.49	0.89
Depth of sand, inches	30	34	27	57	27
Effective size of sand, millimeters	0.40	0.43	0.51	0.46	0.70
Uniformity coefficient of sand	1.50	1.65	1.47	1.40	1.30
Diameter of holes in strainer system, millimeters	1.60	0.71	1.09	0.63	0.61
Percentage which holes in strainer system are of filter area	0.26	1.44	6.00	1.20	8.30

The Pittsburg and Louisville experimental filters may be regarded, in a certain sense, as prototypes of the Little Falls filters, and it is interesting to note the changes from the earlier designs.

The coagulating-basin capacity at Little Falls is increased. Undoubtedly this change is most advantageous, and it may be questioned whether still further increase would not be desirable. The best size for the coagulating basin depends almost entirely upon the character of the raw water, and a size most advantageous for one water might be quite inadequate for another.

In the depth of sand there is but little change, although the very deep layer used in the Jewell filter at Pittsburg has not been repeated. The sand is slightly finer than in the earlier filters, but the change is not important, and the uniformity coefficient, which was insisted on rigidly at Little Falls, is about the same as in the earlier filters.

The size of the holes in the strainer system is much greater, but the total area of the holes is reduced. The large size of opening is only possible in connection with the considerable gravel layers at the bottom, and these layers are no doubt necessary with the smaller total area of the openings.

The ample area of the exit holes in the Warren filters has much to commend it. If the action of filtration was all that had to be considered, the size would hardly have been reduced below this figure. The disadvantage of the large strainers is in the washing. With them there is not sufficient control of the points at which the wash-water rises through the sand. The only way that this has been controlled adequately has been to restrict the sizes of the openings in the strainer system, until so much head is consumed in forcing the water

through that a good distribution of the water is secured over the whole of the area. In the Jewell filters, this was secured by taking the water through necks immediately below the strainer outlets, these necks having an area of only approximately 0.07% of the filter area. This arrangement secured a very good distribution of wash-water, but was open to the objection of having an abnormally high friction for both the entering and leaving water. Mr. Hazen.

In the Little Falls design, the holes in the strainers themselves represent the greatest amount of contraction, and the area of these holes, while much less than the area of the holes in the Jewell strainer systems, is three or four times as great as the area of the necks back of those holes.

The strainer system serves two widely different uses. In normal operation, it collects and removes the filtered water; in washing, it distributes the wash-water; and the distribution to all parts of the filter bottom must be substantially equal. The requirements of the two services are quite different, and the strainer system is a compromise between the requirements of each. The speaker has often questioned in his mind whether the best possible results could be secured without using separate systems for the two services.

The most important point of divergence from the earlier designs is the substitution of air for agitating the sand during washing for the rakes driven by power, which served this purpose in all the earlier filters. Air agitation has been used on many smaller filters, but not before where the results were actually recorded and made available for study by those interested in the art of water purification. The air agitation has the advantage, in its ready applicability to rectangular masonry filters, and in avoiding the necessity of having power and shafting over the filters. It seems to work well at Little Falls, and the present indications are that it may largely supersede other forms of agitation.

The excellent manner in which concrete has been used in all parts of the design is most creditable to the constructing engineers.

J. P. A. MAIGNEN, Assoc. Am. Soc. C. E.—The expression "ripening" of filters has been used by Mr. Fuller, and the speaker would like to ask him and Mr. Hazen what, in their opinion, is meant by it. Is it that the surface of the grains of sand becomes more or less covered by water bacteria, and do these bacteria help the act of purification in any other way than by blocking the interstices between the grains of sand; or, on the contrary, are we to understand that a sand filter becomes "ripe" or capable of giving a good bacterial effluent when the sand has been deprived of the air germs it contained before any water had been passed through the filter? In other words, does the "ripening" imply the addition of water bacteria to the sand, or the elimination of air germs from the surface of the sand grains by a more Mr. Maignen.

Mr. Maignen. or less prolonged flow of water? Some light on this subject might not be without interest.

This brings us back to a statement made by the speaker in discussing the topic "The Decolorization of Water,* when he cited some experiments he had made during several months with filters containing granular materials—sand and charcoal. In both cases practically sterile water was applied (from 8 to 20 bacteria per cubic centimeter). The effluent, during the first two or three days, had from 100 to 300 bacteria per cubic centimeter, and, day after day, although the applied water was always the same (not averaging more than 15 bacteria per cubic centimeter), the filtrate went on showing an ever increasing number of bacteria, until the fifteenth day, when it had reached upwards of 5 000. Then the number of bacteria in the effluent began to fall off, until, at the end of the month, the filtered water did not contain more than the applied water (about 15 bacteria). Therefore, it took one month to "ripen" these filters. They were kept in operation for more than three months afterward, and during all this second period—that is, after the filters had been "ripened"—the applied water never contained less than 2 000 bacteria, sometimes it contained 5 000 or more, and the filtered water never contained more than 20.

How can the large number of bacteria found in the filtered water during the first fortnight be accounted for? It cannot be, as has sometimes been said, that the granular materials are favorable to the development of water organisms introduced with the applied water, because, in this case, the applied water was practically sterile. If the theory of the multiplication of the bacteria in the filter were attributed to the accumulation of mud, how was it that, all of a sudden, and forever after a certain time (nothing being done to sterilize the materials), the number of bacteria in the filtered water went on diminishing daily until it became as low as in the applied water and continued practically sterile for months, although the applied water after the first month contained a very large number of bacteria?

A plausible explanation is to be found in the fact that when granular materials—sand or charcoal—are new the grains are surrounded with dust partly made up of dry germs. These dry germs may be compared to dry seeds, which, as pointed out by Tyndall, when in contact with water, are softened and incubated, as it were, and they become full-grown bacteria. In this state of life they either go out with the filtered water, or die in the sand without progeny.

The speaker, therefore, suggests that the true explanation of the "ripening" of filters is to be found in the gradual elimination of the original or "constitutional" germs existing in materials which have been exposed to the dust of the air previous to being used in filters.

Some of the speaker's experiments would appear to strengthen this

* *Transactions*, Am. Soc. C. E., Vol. XLVI, p. 168.

view. One of the sand filters which had been "ripened," as already explained, and was giving perfectly pure water during more than one month, was placed out of service, the old sand was carefully taken out and a thin layer of small pebbles, which had not been washed or used before, was placed at the bottom of the filter, and the old "ripe" sand put back again over the pebbles. During the following days the filtered water became very rich in bacteria, and it was more than a fortnight before the filtrate was as free from bacteria as the applied water. Mr. Maignen.

The ripening of filters, therefore, would seem to consist in freeing the sand from air germs and not in charging it with water bacteria. This is but an idea, for which the speaker has given his reasons, and it is submitted for consideration.

C. L. HARRISON, M. Am. Soc. C. E.—This paper presents the modern design and construction of the mechanical filter, and is a valuable addition to the literature on the subject of water purification. The construction is substantial and cleanly, and the design is in accordance with the best recent knowledge of this subject. Mr. Harrison.

There is one marked difference between the design of this plant and of those which were constructed a few years ago. In the older plants the coagulant was introduced directly into the filtering tanks, while in this one it is mixed with the raw water, which is then allowed to pass through a subsiding basin, from which it is taken to the filtering tanks. This is an important feature of the design, as Table No. 4 shows, for the months of October, November and December, 1902, and January, 1903, that 83, 68, 67 and 58%, respectively, of the bacteria in the raw water were removed before the water left the subsiding basin; and, in addition to this, the sludge is deposited in this basin, instead of in the filtering tanks, where it would clog the sand and necessitate more frequent washings. Some experiments made by the speaker a few years ago show clearly the great value of the subsiding basin, and indicate that one large enough to require more than one hour for the water to pass through it would be desirable. The effect of the basin would be increased very much by taking the water from it at points near the surface. The plans do not seem to indicate how this is done, and perhaps the author will give some further information on the subject. By using a subsiding basin of proper size, the action of the coagulant can be entirely completed before the water reaches the filtering tanks, and the sludge be deposited in the basin, thus increasing the efficiency of the plant in removing the bacteria and reducing to a minimum the quantity of wash-water required.

J. WALDO SMITH, M. Am. Soc. C. E.—Since the end of the six months' experimental period mentioned in the paper, there has been one month of normal operation of this filter plant. During that month—March, 1903—the quantity of coagulant was about 15% in excess of the expected average. Mr. Smith.

Mr. Smith. The average quantity of wash-water has been about normal; and the plant has been operated at about one-third of its normal capacity.

The cost per million gallons of filtered water delivered into the pipes (wash-water deducted) has been as follows:

Labor	$1.22
Coagulant	1.60
Heat	0.25
Power	0.12
Total	$3.19

If the quantity of water filtered were twice as great as at present, the labor item in the above cost would not be increased. The cost of coagulant would be in proportion to the quantity of water filtered, and the heat and power items would be increased only slightly. In fact, the heat item for March is greater than the average per month throughout the year.

Under these conditions, which will probably obtain within a year, the cost per million gallons would be about $2.50, instead of $3.19, as stated above.

Mr. Weston. R. S. WESTON, Assoc. M. Am. Soc. C. E.—This excellent paper presents few points which can be criticized unfavorably.

Passing by the discussion of the construction of this intricate monolith, and considering the operation of the plant, one is impressed by the care taken in the design to have everything convenient for the operator. Those who have had to do with the operation of rapid filters have been impressed by the great loss of time and consequent cost incurred for the opening and closing of valves during the washing of the sand layer; but when one goes to Little Falls and sees how easily the filters are operated, how little labor is performed to obtain the required results, he is filled with admiration for the work.

The speaker has made several visits to Little Falls, both during the construction and during the operation of the filter plant, and he doubts if any municipal structure, built during the last few years, has had in it so few things which have had to be changed after the completion of construction, notwithstanding that the Little Falls construction represents many new departures.

The chief of these departures—the use of air as an agitator, during the washing process—permits the rectangular construction of the filter tanks, thereby enabling one to increase the size of the units (tanks) and to abandon the short-lived mechanical agitator and the space-consuming, round filter tank.

The speaker happened to be in Little Falls before the gravel was put into the filters, and while the air and water distribution systems were being tested. The efficiency of these devices was excellent. The water appeared at every strainer at about the same time, and the

spray from the strainers appeared to cover the whole bottom of the filter, when viewed from above. The air, also, was well distributed. Mr. Weston.

The gain in efficiency at Little Falls due to the use of air agitation is well shown in the tables. Whether this agitation by air or by means other than water currents is necessary in all filter plants—that is, enough to justify its cost—is a question. The water at Little Falls might be called fibrous. It contains much vegetable and amorphous matter, which makes a felt on the sand layer during filtration, and which must be removed continuously with each washing, in order to maintain the sand layer at its highest efficiency. The use of air agitation breaks up this felt and the concretions of aluminum hydrate, amorphous matter and sand, and reduces all the matter to particles of such a hydraulic value that they can be removed more readily, subsequently, with the wash-water. Whether agitation would be necessary with a water containing only crystalline, silty and finely divided suspended matter (which does not seem to form a mat or felt on the surface of the filter), and where the expense of the agitator is a consideration, must be left to the future and to the larger plants for its solution.

Certainly, the experience which will undoubtedly be gained from the operation of this plant will establish the system of rapid filtration upon a firm, rational and scientific basis, and it must be felt by all that, at least after the proposed plants at Louisville, Cincinnati and New Orleans are completed, it will be possible for engineers to design rapid filters with little or no chance of failure, provided all the local conditions are studied carefully.

Regarding the preparation of sand for a rapid filter, the speaker agrees with Mr. Fuller that it is necessary to have a uniform sand, of medium size, practically free from particles finer than 0.25 mm. in diameter. To obtain sand of this character is a hard task. Of late the speaker has been attempting to devise an apparatus for the removal of the fine particles, the "dust," from a lot of sand. This means that all particles which would pass through wire-cloth with 80 meshes to the linear inch must be removed. Given, dry sand, it is a simple problem to separate particles which would pass through a screen with 60 meshes to the inch, but a much more difficult one if finer screens are tried.

Thinking that, perhaps, the best method was to dry the sand and pass it through a screen, the speaker designed a hexagonal rotary screen, 4 ft. in diameter and 9 ft. long. The frame of this device carried two concentric, hexagonal, wire-cloth screens, the inner of No. 20 and the outer screen of No. 80 mesh. The screen made about thirty revolutions per minute. It was cleaned, from the outside, by a jet of compressed air.

The sand was heated to a temperature of from 300 to 400° Fahr.,

Mr. Weston. and was thoroughly dry. It was then fed into one end of the screen at the rate of about 22 cu. ft. per hour. The results were unsatisfactory. The fine screen clogged quickly—so quickly, in fact, that it became useless after a few days. For the first three or four days, with constant watching, one could get proper sand at a cost of about $10 a cubic yard; and, by the way, $10 a cubic yard is not a high estimate for rapid-filter sand. At present a winnowing-device is being tried; the first work is satisfactory, and the cost of operation reasonable. It is hoped that the solution of the problem lies along these lines, as separation by hydraulic means is practicable only where water is cheap and abundant.

This paper reflects great credit on its author, his associates, the filter company and all others concerned in the design and construction of this excellent work.

Mr. Whipple. GEORGE C. WHIPPLE, Assoc. M. Am. Soc. C. E.—The speaker has been privileged to follow the construction of the Little Falls filter plant from the beginning, and to witness its successful operation. To say simply that it is a success would be faint praise, indeed. It is the first adequate demonstration of the principles of mechanical filtration applied on a large scale, and its many unique features distinguish it sharply from the conventional type of mechanical filters used heretofore.

Among the features which have interested the speaker especially are those which appertain to the filter proper, namely, the sand, the gravel, the strainer system, and the application of compressed air as an aid in sand washing. These details seem to have been arranged with great care, and, in themselves, are sufficient to render this plant unique.

The fact that so little sand has been lost during the washing process is proof, not only of delicate design, but of careful operation. This fact appeals to the speaker all the more strongly, perhaps, because he has recently had experience with a mechanical filter in which the quality of the sand was poor and the method of sand-washing was imperfect. In this plant the compressed air and wash-water were applied to the bed simultaneously, with the result that in a short period of a few months' time so much fine sand was lost that the effective size increased from about 0.30 to about 0.60. It is certainly more scientific to use sand of a proper size and adjust the wash-water conditions so that no sand may be lost than it is to use a cheap, improperly graded sand and depend upon the wash-water to remove the fine material.

The speaker agrees with those who have already spoken that it is a matter for congratulation that the Little Falls filter has been tested so carefully. While many data are available for experimental plants, there are comparatively few mechanical filters which have been tested

adequately. It is only by the publication of such results that the popular prejudices against mechanical filters can be swept away. Take, for instance, the matter of alum. The speaker supposes that there is no engineer who has recommended the installation of a mechanical filter but has had to contend with the popular prejudice against the use of alum, and who has not been told, in cities where such plants have been installed, that the consumers could taste the alum—sometimes even before it was used. Mr. Whipple.

The fact that it is possible to prevent undecomposed alum from passing through a mechanical filter, even though the alkalinity of the original water be low, is demonstrated by the five thousand tests which have been made at Little Falls. This is something to which engineers can "point with pride," and the operators can take as much credit for this as the engineers. Indeed, it cannot be stated too emphatically that the successful operation of a mechanical filter is dependent upon the conscientious and unflagging attention of the operators, night and day, day in and day out. No mechanical filter will run itself. Even automatic devices must be watched. But, while the element of human fallibility is introduced in the operation of a mechanical filter, more, perhaps, than in the case of a sand filter, it must be remembered that locomotives and steam pumps and boilers need to be watched, and so does every form of machinery. It is no more difficult to care for a filter than to care for pumping machinery, and, with the same class of operators and with suitable filters, periods of imperfect filtration ought not to be more common than railroad accidents. Just as the country has developed a class of men skilled in firing boilers and running engines, so there must be developed a class of men skilled in operating filters. At the present time there is no more promising field for a young graduate engineer than that of superintending the operation of filter plants. Such men need to have some knowledge of chemistry and bacteriology—enough for them to carry on certain simple tests of the water before and after filtration—and they should understand the principles of hydraulics and be of a mechanical turn of mind. It is hoped that our engineering schools will take this subject into consideration and see that their students have proper instruction in the operation as well as in the design of filters.

WILLIAM B. FULLER, M. Am. Soc. C. E.—As has been well said, the completion of this plant stands as a milestone marking distinct progress in the art of mechanical filtration. In a lesser, though still distinctive, way it stands as a milestone from a constructive point of view, in that it has been constructed throughout almost entirely of concrete. This has been done with an idea of making the entire structure as durable and permanent as possible, and it is this part of the work to which the speaker now wishes to refer. Mr. W. B. Fuller.

The substructure of the plant, that is, the portions acting as

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coagulating basins and clear wells, is built as a gravity section of concrete in mass, without iron. The filters over the clear well, the walls of the building proper, and of the monitor, are also built of concrete, with steel rods embedded throughout the mass. All floors and partitions, as well as the benches and chemical hoods in the laboratories, stairways between different levels, mixing, solution and chemical tanks, and columns and girders throughout, are also of concrete construction.

In relation to this construction there are a number of unusual features. The floor over the coagulating basin is designed for a load of 350 lbs. per square foot, and consists of two spans of 24 ft. each, the interior ends of the floor beams resting on concrete girders, resting in their turn on concrete columns from the bottom of the basin 43 ft. deep. These columns average 42 ins. square, and sustain an exterior load of more than 10 tons per square foot. This is possibly as tall a column for sustaining such loads as has yet been constructed of concrete. The floor of this basin, while designed to carry 350 lbs. per square foot, has frequently to carry a loaded cart, the concentrated load on each wheel being about 1 500 lbs.

In one portion of the plant there are two mixing tanks, which are 16 ft. in diameter and 16 ft. high, each containing about 25 000 galls. of water. They are round tanks, made of concrete 12 ins. thick, the concrete surrounding an iron skeleton. These tanks are tight and safe with water inside pressing outward or with water outside pressing inward. They are also set upon the top of concrete posts, about 30 ft. above the floor of the coagulating basin.

The stand-pipe, or tank into which the river water and the coagulant first enter, is 10 ft. in diameter and 43 ft. high, and it is tight with a water pressure either inside or outside. It is made of concrete, 15 ins. thick at the bottom and 10 ins. thick at the top, the concrete being reinforced with iron rods embedded therein. This entire tank was built in 8 hours, all the concrete being placed from the top, and thus falling the full depth of 43 ft. when the tank was first started. This is contrary to the ideas of a great many engineers in regard to proper concrete construction, that is, to put in a depth of 43 ft. of concrete continuously without stopping.

This concrete was put in very wet, a wheel-barrow load (5 cu. ft.) at a time, and was merely joggled to position. When the forms were removed the surfaces were absolutely smooth, not a stone or a void showing. It had been intended to plaster the inside surface of this tank to make it water-tight, but the plastering was omitted as being wholly unnecessary.

An interesting part of the construction is the suspending of the steel pipes, 66 ins. in diameter, and full of water, from stirrups fastened to the concrete floor-beams.

These pipes when full weigh more than 1 ton per linear foot, and convey the water from the coagulating basin to the filters; for a part of their length they are protected inside with a cement lining. Mr. W. B. Fuller.

The filters themselves, of which there are thirty-two, were built under a guaranty as to tightness and strength, the minimum sections of concrete and metal having been specified before bids were received. As these tanks are situated directly above the clear-water basin, it was essential that they should be absolutely water-tight. This result was secured, as a trip around the clear-water basin in a boat failed to detect any dripping from the filled tanks above. This result was secured first by building each tank as a monolith, the bottom, sides, and top, all at one continuous operation. They thus became for all intents and purposes like a nest of boxes, each box being free to move by itself under varying stresses. Each tank was also plastered on the inside first with a ¼-in. coat of 1 to 1 cement-and-sand mortar and then a ⅛-in. coat of neat cement mortar. This last coat, below the sand level, was stippled with a stiff corn broom, so as to make the surface very rough, to prevent the passage of water between the sand and concrete sides, rather than through the sand.

The concrete in the lower part of the structure was made in the proportions of 1 part cement, 3 parts sand and 7 parts stone, which are rather unusual proportions for water-tight work under heads up to 43 ft. The idea, when the specifications were made, was that it would be best to make a water-tight lining on the inside of the basins with a very rich concrete, and make the outer part of the wall with a poorer concrete, in order to save cost, the theory being that if the inner lining leaked, it would be best to have such water pass out through the back of the wall.

In actual construction, however, it was found that the 1 : 1¼ : 3 concrete—the very rich concrete—which was used for the lining, was very difficult to place, and, as placed, it actually was not as tight as the 1 : 3 : 7 concrete. The latter was absolutely water-tight, as far as permeability is concerned. What leaks there are in the plant are very few, and they have always occurred in joints or at cracks due to temperature. A great deal of care was taken in the grading of the sizes of the sand and stone, so as to have the voids filled very thoroughly before any cement was placed in the mass.

L. L. Tribus, M. Am. Soc. C. E.—It seems that the past has demonstrated that filtration can be effective for the almost absolute removal of sedimentary and deleterious organic matters in public water supplies, and it is also fully evident that many surface-water and some ground-water supplies, as well, will soon have to be filtered. Mr. Tribus.

There can be no question that with proper care either the "rapid" or "mechanical" process, or the "slow" or, as ordinarily described, "sand process," will be effective; one being, however, more of a

Mr. Tribus. straining method, the other probably more thoroughly bacteriological, and so, perhaps better, from a strictly sanitary standpoint.

An interesting question, not largely investigated as yet, but to which special attention should be given at an early date, is whether water treated by the "rapid" process will keep longer in storage without spoiling than that treated by the "slow sand process" (the chemicals generally used with the former ought never to be in such excess as to be in themselves a factor). Thus far, it has been deemed most expedient to keep all filtered waters in covered storage reservoirs and in relatively small quantities at that, but as filtration comes into more general use it will be found, in many instances, very desirable to have the processes carried on near the sources of supply, and the filtered water delivered to existing large open reservoirs near the point of use. If all filtered water is going to deteriorate seriously with such "open storage" more rapidly than would unfiltered water, then filtration has not yet reached the point of development which it must reach for universal application. If the same water will keep longer in good condition after being filtered by one of the main processes, then that process will control the general situation.

At the plant under discussion, test analyses of the raw water, the water in the coagulating tank and in the filtered-water basin, have been made systematically, with, perhaps, a few analyses of the water from the tap as delivered some miles away. The results seem to have been eminently satisfactory, but what would the result be if this same water, prior to its use, should be stored for several weeks after filtration, in an open reservoir? The question can only be answered by experiment, and it is to be hoped that such test, along the line suggested, will be made by the company whose plant has been so well designed and so interestingly described by Mr. Fuller.

Mr. Pearse. LANGDON PEARSE, Jun. Am. Soc. C. E. (by letter).—There is one point in Mr. Fuller's admirable paper which is not clear to the writer. He has been unable to find any statement concerning the co-ordination of the rate of application of the alumina sulphate solution to the flow of raw water through the "alum" grid. To vary the application of the alum solution properly, some device is needed. In the writer's brief experience with a small municipal filter plant, a case occurred where the quantity of alum added to the raw water was entirely too small, simply because of the impossibility of measuring the flow of the raw water as it passed the outlet of the alum feed. The alum had to be regulated by the pumpage from the clear-water well, which by no means corresponded to the flow of raw water into the settling basin during the same interval.

Mr. Gregory. JOHN H. GREGORY, Assoc. M. Am. Soc. C. E. (by letter).—Thanks are due, not only to Mr. Fuller for his valuable paper on the Little Falls Purification Works, but also to Mr. J. Waldo Smith, Superin-

tendent and Engineer, and to the other officers of the East Jersey Water Company, for allowing the publication of such a complete description of the plant, and especially of the results accomplished during its first few months of service. The writer knows of no place where so much valuable information requisite for designing a mechanical filter plant properly is available as is given in condensed form in this paper. Mr. Gregory.

The writer visited the construction work several times during its early stages, and was fortunate enough to be located so that he could visit the plant frequently during the latter part of the construction, as well as since it has been put in service, and he has made the most of these opportunities to study the construction and operations in detail. The type of construction adopted at Little Falls is radically different from that used heretofore for mechanical filter plants, and, in the opinion of the writer, is a great improvement over that used for certain other plants built recently. The design of mechanical filter plants in the future will, it is to be hoped, be modeled, in general, closely after the Little Falls work.

The writer is a strong believer in very wet concrete, and it is especially interesting to note that the concrete in the main construction at Little Falls was mixed so wet that the workmen had literally to wade through it. Concrete thus mixed requires very little tamping, rather a joggling of the whole mass into position, and the engineer can feel assured that he will get a satisfactory piece of work, and that when the forms are taken down the exposed faces will present a smooth appearance and be free from voids. This smooth appearance was characteristic of the work at Little Falls. Although it is impossible now to inspect very much of the heavy walls, yet certain portions are still exposed, namely, those shown below the superstructure in the views on Plate XXXVI, and a visitor to the plant who is interested in concrete construction will be well repaid by examining these walls carefully. They have not been touched in any way since the forms were first taken down.

It is common practice in filter construction to take certain precautions to prevent the raw water from passing down too rapidly alongside the walls. At Little Falls, as has been stated, the inner walls in the filter tanks below the sand surface were roughened by stippling with a wire brush before the plastering had set. The surface thus produced was very rough, and, in fact, for the end desired, was the most satisfactory surface which the writer has ever seen.

In designing the concrete walls and piers for the slow sand filters at Philadelphia, the writer advocated a slightly different method of procedure. The exposed faces of the piers and walls below the sand line were to be floated with a thin plaster of Portland-cement mortar, and then, before this plaster had set, were to be dashed with sand.

Mr. Gregory. The necessary clauses providing for this were inserted in the specifications. After the construction was under way, of course the attempt was made to carry out this provision of the specifications. The writer was not in charge of the construction, but visited the work frequently to watch its progress and the methods used by the contractors. The sanding of the surfaces, as actually done, could hardly be said to be satisfactory, but, in the opinion of the writer, this was due entirely to the method of doing the work. The writer had seen surfaces elsewhere which had been finished rough by being dashed with sand, namely, the coping and exposed faces of small concrete retaining-walls, and surfaces similar to these the writer had in mind when the specifications were written. Recently, he has heard that the attempt to sand these surfaces has been abandoned, and that they are finished smooth, but trusts that he has been misinformed in this particular. In his opinion it would be much better to leave the rather rough surface produced by the common wooden float than to trowel them smooth; or, better still, to roughen them by stippling with a wire brush, as was done at Little Falls.

The idea of using hydraulic valves instead of the ordinary hand-operated valves was a happy one, and, at a glance, will be apparent to anyone who can watch the daily operations at Little Falls and at other plants. The ease with which the valves are controlled was brought home to the writer very forcibly a few weeks ago. He had occasion to conduct a series of experiments at a mechanical filter plant in which it was necessary to open and close a valve at frequent intervals to control the supply of water. The valve had the ordinary hand-wheel, and it turned very hard, as the stem was bent slightly.

All took turns at handling the valve, and the time and labor consumed was anything but pleasant, to say nothing of the comments which were forthcoming.

The use of air for agitating the sand layer has proved successful. Many times the writer has watched the application of air to the various tanks, in the ordinary operations of washing, when the tanks have been only partly filled with sand, and with no sand when the strainers have been covered with only a few inches of water. When the air is turned on, it naturally finds a relief through the nearest outlets, and the thought passes rapidly through one's mind, "Will it come out all over the bed?" But this is answered at once by the almost instant agitation of the water surface at all points, and, as far as the eye can judge, with a perfectly uniform distribution.

The experiments indicate that at Little Falls the use of air for agitation, in addition to that produced by the wash-water, is of advantage; but it may be that at some other place, with a different water, the air could be dispensed with, reliance being placed on the wash-water alone. Engineers, however, would hesitate to design a plant to

operate under such conditions without first having demonstrated its feasibility by a series of carefully conducted experiments. Mr. Gregory.

The Little Falls plant is thoroughly up to date, but experience indicates that here, as with nearly all work, improvements can be made. In the case in question, however, they are entirely of a minor nature, and do not affect the work as a whole.

L. J. Le Conte, M. Am. Soc. C. E. (by letter).—The writer is greatly impressed by this excellent paper, and particularly by the results obtained. Mr. Le Conte.

The first thought which strikes one, in looking over and considering all the existing conditions, is why did they make such a selection? The author seems to explain it in a plausible and reasonable way, but the fact still remains that, from a sanitary point of view, it might have been otherwise. The prevalent tendency nowadays seems to be a wild chase to get a clear, sparkling filtrate, irrespective of the bacterial efficiency of the filters. This unfortunate feature—like the fashions—will have to run its natural course. It must be admitted, however, that the bacterial efficiency, as shown in the December record, is very fair indeed—for mechanical filters—and is far ahead of the writer's expectations in the matter.

As far as clarification is concerned, mechanical filters have certainly earned the palm, fairly and squarely, but, from a sanitary point of view, everything seems to indicate that the old-fashioned sand filters do the best and safest work. The best information we have in regard to the health improvement of towns and cities certainly leads directly to the results obtained from actual experience with sand filters. It is true that the bacterial efficiency given by the author for the month of December, 1902, promises well; but the raw river-water was only slightly polluted at the time, and hence we are still left in serious doubt as to the efficiency from a sanitary standpoint. The bacterial efficiency of mechanical filters, after all, depends absolutely and entirely upon the continuous application of the coagulant in the proportion which the raw water calls for, and this proportion is a quantity as variable as the winds. Here is where we find the great stumbling block to the proper working of mechanical filters, and this fact explains many of their failures, heretofore.

The new devices invented and applied for controlling the feed of the coagulant in this plant seem to be a great improvement over former designs, and the author certainly deserves much credit for them and their good work. Granting all this, they have, nevertheless, not yet reached anywhere near perfection, as admitted by the author, and as instanced by the bacterial record. The lowest efficiency obtained has invariably followed the failure to secure perfect operation of the coagulant feed.

Another important feature is the constant variation in the alka-

Mr. Le Conte.

linity of the river water. At certain intervals, determined by analysis, it becomes necessary to add some alkali (soda) to the water, in order to insure complete decomposition of the applied coagulant, otherwise there would be free alum in the filtrate, which would never do. All these things require the services of experts of a high class, and demand the closest possible attention and the most painstaking care in order to secure fairly good results. Finally, if all these technico-chemical features can be practically solved—and the writer has his doubts about it—then, and not till then, can we frankly say that mechanical filters stand on the same footing with the long-tried, old-fashioned sand filters.

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GEORGE W. FULLER, Assoc. M. Am. Soc. C. E. (by letter).—Referring to the capacity of the coagulating and settling basins, in purification works of the Little Falls type, mentioned by Mr. Hazen and Mr. Harrison, it is unquestionably advantageous to make them of relatively greater size than was the custom several years ago. In the Little Falls design the size of the coagulating basin is such that with certain types of water found elsewhere the filters would doubtless be operated more easily if the basin were larger. The general effect of a larger basin is to make the periods of service between washings longer, and thus reduce somewhat both the labor in operation and the percentage of wash-water. At this particular place it was not considered, nor is it now believed, that the resulting reduction in wash-water and labor would be sufficient to offset the fixed charges on the investment necessary to increase materially the size of the basin. Of course it is true, however, that conditions at Little Falls are quite unusual as regards the depth and the relative cost of the coagulating basin, the limited area of ground available for extension, and the fact that for the greater portion of the time power for pumping the wash-water is furnished from the water-wheels.

As to the removal of the water from the coagulating and settling basins, those plans which have been reproduced do not seem to indicate this clearly, as was pointed out by Mr. Harrison. It is stated in the text, however, that the water is removed from near the surface at the southern end, that is, the end opposite from the stand-pipe through which the raw water enters at the bottom.

Concerning the point mentioned by Mr. Pearse, regarding the coordination of the application of alum solution to the flow of raw water through the "alum grid," the flow of water through this plant is by gravity, and the rate of flow is regulated automatically by the Weston controllers attached to the outlet pipe of each filter which is in operation. There is no material change in the water levels in the filter tanks or in the coagulating basin, and hence the volume of water to be treated is readily obtained from noting the number of filters in service. Knowing the volume of water to be treated, the rate of treatment de-

sired, and the strength of the solution in use, the volume of sulphate of alumina solution to be applied and the corresponding length of opening in the orifice tank are indicated readily by tables or curves. Mr. G. W. Fuller.

The strainer system at Little Falls serves not only the double purpose of providing for the removal of filtered water as well as for the introduction of wash-water, but it may be stated that it serves a triple purpose by making provision, in addition to the two features last stated, for the introduction of air used in agitation during cleaning. As suggested by Mr. Hazen, it is possible that advantages may result from the separation of the devices serving these several purposes.

The arrangement of the strainer system at Little Falls, as stated, is considered to serve its purpose reasonably well, practically speaking. It can hardly be stated, however, that it is now in an ideal stage of development, owing to difficulty in keeping the gravel layers in their original position. At this time (July 15th, 1903), the gravel layers show considerable variation in thickness, and in some instances they have become removed immediately above the tops of the cylindrical strainer cups. Some sand has passed through the strainers, outlet piping, controllers and down into the clear-water basin. The amount to date would probably equal about $\frac{1}{4}$ in. in thickness over the entire area of the sand surface of those filters which have been in service. Shifting of the gravel layers seems to be due to a rolling action, more or less cumulative in its nature. It is not only irregular, in that ridges of gravel are formed in different places in the different filters, but it is to be noted that there has been ridging of the gravel layers in those two filters (Nos. 13 and 16) which have never received air since regular operations began. It is believed that this result has been brought about, not so much by normal operations as by unusual conditions, some of which may have been incident to the preliminary working of the plant prior to its going into regular service, and some to the use of wash-water and of air under rates of application which were too high, or under pressures which were too high, during the early days of service of the plant. It is now proposed to level these gravel layers and increase their thickness several inches by the addition of coarser material at the bottom.

The expression "ripening of filters" has been used by the writer in the sense of the formation of films around the sand grains in such a manner that the sand bed would assume what may be called a normal condition as regards facilities for matters suspended in the water to be removed by adhesion and friction. The experience referred to by Mr. Maignen, in which the so-called original or constitutional bacteria were obtained in the effluent of a sand filter for many days after the application of water, and in numbers exceeding those in the applied water, is not a new or unusual one. It was encountered at the Lawrence Experiment Station, as indicated in the 1894 volume of the report of the

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Massachusetts State Board of Health, page 589. From the writer's standpoint, the question of ripening filters is not ordinarily one of freeing the sand from the germs contained in it and charging it with water bacteria, but one of getting the physical features, that is, the films around the sand grains, in normal condition.

The question of the storage of filtered water, as mentioned by Mr. Tribus, is one about which the evidence in this country is limited to-day. Speaking generally, we know that clear waters are harder to store and keep in good condition than raw waters which are turbid from either silt, clay or vegetable matter. The storage of ground-water in open basins or tanks for a long period is generally an unsatisfactory procedure. It is ordinarily less difficult to store filtered water of surface origin than it is ground-waters, but there is considerable soundness in the proposition, advanced and held by many, that after water has been carefully filtered it is not wise to run risks of its deterioration, by exposing it to the atmosphere and to sunlight, if it is practicable to avoid it.

For how long a period it is feasible to store a given filtered water cannot be stated definitely from present evidence. Storage for a period of one or two weeks at Lawrence and at Albany suggests that under certain conditions it is a much less difficult problem than indicated by experience elsewhere. How far the proposition is affected by the type of filtration is somewhat uncertain. The effluent of mechanical filters, generally speaking, is somewhat clearer than the effluent of sand filters, thus allowing the sunlight to penetrate to a somewhat greater depth. As far as organic matter, in either a dead or living condition, is concerned, there is probably not very much to choose. The effluent of sand filters is apt to contain more nitrogen in the form of nitrates, other things being equal, than is the effluent of mechanical filters. As regards carbonic acid, another of the principal foods for algæ, the reverse is true, generally speaking. How these various factors balance up cannot now be predicted accurately, and in fact it would seem that differences in local conditions, other than the type of filtration, may perhaps be of more significance than those factors resulting from the method of purification adopted.

Mr. Le Conte seems to possess a considerable feeling of doubt as to whether the Little Falls filters are and will be capable, from a sanitary point of view, of standing on the same footing as the long-tried, old-fashioned sand filters. There are two ways of looking at these matters, as regards evidence suitable to assist in forming an opinion upon the subject. One refers to the analytical results, to show the efficiency of the filters, such as have been obtained daily at the Little Falls plant, as well as at Lawrence, Lorain, Albany, York, Philadelphia and other plants in regular operation, and from various investigations on a smaller scale, of which the principal ones

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are those made at Lawrence, Providence, Louisville, Pittsburg, Cincinnati, Washington, New Orleans, Philadelphia, Harrisburg and numerous others of shorter duration. The other line of evidence refers to death rates from typhoid fever in the communities using the filtered water.

From the analytical standpoint, there is no very decided difference or preference in efficiency between the two types of filters, when both are well constructed and well operated.

Since March 1st, 1903, the Little Falls plant has been under the immediate charge of Mr. Frank W. Green, who has run the filtration works without any assistants technically trained. As has been pointed out in the reports of several of the larger investigations upon water purification, it is quite a burden upon inexperienced filter attendants to secure gauge readings, samples, etc., at frequent intervals on definite schedules, in order to obtain thoroughly reliable data in the study of problems of importance. At Little Falls the significance of this has been clearly demonstrated, because with the cessation of the special investigations, during the first six months of service, of many points aimed at learning the individuality of the filters in the treatment of the local water, the operation of the plant has become much simpler and easier than formerly. This is partly due to the information obtained from the special studies, partly to the familiarity of the attendants with their work, and partly to the smaller demands made on the attention of the filter men.

As to facilities for applying the coagulant solution, no changes have been made since the original paper was prepared, but one or two features of minor importance will probably receive attention a little later on. The results obtained from February 1st, 1903, up to the present time, and which, in conjunction with Table No. 4, cover the essential features of the first ten months of operation of the plant, are shown in Table No. 18.

TABLE No. 18—(*Continued*). DAILY SUMMARY OF LEADING AVERAGE RESULTS OF OPERATION.

Day, March, 1903.	Period between washings. Hours.	Percentage of wash-water.	Sulphate of alumina. Grains per gallon.	Parts per Million.						Bacteria per Cubic Centimeter.	
				Alkalinity.		Turbidity.		Color.			
				River water.	Filt. water.	River water.	Filt. water.	River water.	Filt. water.	River water.	Filt. water.
1	11.06	2.3	0.90	13	7	25	0	29	3	15 700	70
2	11.39	2.4	0.88	12*	5	23	0	25	3	8 900	100
3	9.31	2.9	0.92	13	6	19	0	24	3	9 700	325
4	10.98	2.4	0.67	13	8	19	0	22	3	6 500	230
5	11.09	2.3	0.89	13	7	12	1	25	9	2 800	80
6	9.69	2.8	0.98	20	12	8	0	18	4	3 000	31
7	9.24	3.5	1.09	18	11	7	0	24	3	900	30
8	9.54	3.0	1.09	17	10	12	0	27	5	2 600	21
9	11.95	2.6	1.25	17	8	11	0	25	3	2 300	7
10	9.20	3.1	1.51	16	6	10	0	28	4	750	6
11	10.09	2.9	1.50	17	7	8	0	27	3	900	8
12	9.89	2.8	1.51	17	7	7	0	25	3	750	6
13	10.98	2.6	1.26	17	9	6	0	23	3	800	8
14	8.70	3.6	1.02	16	9	6	0	25	3	500	9
15	8.89	3.0	1.01	21	13	6	0	26	4	400	12
16	8.98	3.1	1.01	23	16	7	0	25	7	600	80
17	6.75	4.3	1.23	22	15	8	0	28	6	550	90
18	8.67	3.2	1.25	23	14	8	0	24	4	700	12
19	8.74	3.0	1.24	23	15	8	0	26	4	850	14
20	9.35	3.2	1.25	24	16	9	0	26	5	900	13
21	8.64	3.3	1.21	25	17	11	1	27	6	1 300	14
22	9.30	2.9	1.12	22	14	12	0	28	6	2 600	41
23	11.32	2.5	1.12	19	11	18	0	29	6	5 500	85
24	10.70	2.6	1.13	16	8	21	0	27	5	3 900	24
25	9.80	2.6	1.12	16	8	21	0	27	6	3 200	27
26	8.82	2.9	1.13	18	10	16	0	26	7	1 500	21
27	9.34	2.8	1.10	18	10	13	1	29	7	800	55
28	10.82	2.7	1.14	19	11	11	0	29	5	1 300	13
29	12.10	2.2	1.13	22	15	11	0	29	6	1 200	16
30	9.26	2.9	1.12	22	14	11	0	29	6	1 700	26
31	10.00	2.7	1.12	22	14	17	0	28	6	1 700	17
Averages	9.86	2.9	1.12	19	11	12	0	26	5	2 700	48

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TABLE No. 18. DAILY SUMMARY OF LEADING AVERAGE RESULTS OF OPERATION.

Day, Feb., 1903.	Period between washings. Hours.	Percentage of wash-water.	Sulphate of alumina. Grains per gallon.	Parts per Million.								Per Cubic Centimeter.				
				Alkalinity.		Turbidity.			Color.			Amorphous matter.		Bacteria.		
				River water.	Filt. water.	River water.	Subs. water.	Filt. water.	River water.	Subs. water.	Filt. water.	River water.	Subs. water.	River water.	Subs. water.	Filt. water.
1	11.28	2.3	0.78	16	11	5	4	0	32	24	5	300	150	11 500	1 900	250
2	12.54	2.2	0.78	17	11	8	7	0	33	20	5	280	170	3 000	1 200	190
3	12.60	2.1	0.90	17	11	8	8	0	30	17	4	250	160	3 400	1 500	170
4	11.40	2.3	1.26	18	11	9	6	0	39	18	4	220	200	3 300	1 800	35
5	9.73	2.7	1.32	15	8	18	9	0	39	22	5	300	140	6 600	2 400	20
6	9.59	2.7	1.21	15	7	16	9	0	37	24	5	280	120	6 000	2 800	24
7	10.56	2.9	1.18	16	7	20	15	0	39	26	3	260	170	3 800	1 900	28
8	13.61	2.1	1.24	16	8	16	11	0	36	25	4	320	220	2 800	1 200	27
9	9.43	3.0	1.11	17	9	12	10	0	35	26	5	300	180	2 100	800	35
10	11.90	2.3	1.13	16	10	9	5	0	35	19	5	300	150	1 100	450	18
11	10.08	2.7	1.12	17	9	12	10	0	34	19	4	350	180	1 500	350	48
12	13.13	2.1	1.01	18	11	20	6	0	28	22	6	410	240	2 400	1 300	140
13	10.44	2.6	1.11	15	8	17	16	0	30	24	5	320	200	1 500	600	29
14	11.03	2.7	1.14	14	6	13	9	0	30	21	5	300	180	1 600	500	22
15	11.17	2.6	1.12	15	7	11	9	0	31	22	6	270	140	2 100	230	21
16	7.02	4.2	1.12	16	8	11	8	0	30	22	5	250	130	1 900	160	16
17	7.05	4.0	1.00	16	11	14	7	0	27	21	5	230	130	1 200	190	19
18	8.63	3.2	1.10	17	19	12	6	0	29	18	5	200	100	650	325	55
19	7.32	2.7	1.15	19	11	14	7	0	29	18	4	250	180	1 000	400	70
20	7.81	3.5	1.05	20	13	9	6	0	27	18	6	210	160	750	350	17
21	8.43	3.1	1.08	21	14	8	6	0	28	17	5	200	140	800	275	25
22	8.80	3.2	1.17	22	15	7	6	0	26	17	5	220	140	...	.....	..
23	9.00	2.8	1.08	23	15	9	8	0	25	17	5	260	150	.....	.....	..
24	8.24	3.1	1.10	24	16	8	6	0	24	17	5	250	130	3 900	550	24
25	5.86	4.6	1.58	24	17	9	7	0	23	16	5	220	120	2 500	600	65
26	7.32	3.6	1.19	25	19	8	8	0	25	17	4	200	100	3 200	1 700	75
27	10.79	2.5	0.99	25	19	9	7	0	25	16	5	180	100	10 300	2 100	120
28	8.51	3.0	0.99	21	14	17	7	0	26	14	3	250	130	7 800	3 800	130
Averages	8.76	2.9	1.14	18	12	12	8	0	30	20	5	260	150	3 600	1 100	70

TABLE No. 18—(*Continued*). DAILY SUMMARY OF LEADING AVERAGE RESULTS OF OPERATION.

Day, April, 1903.	Period between washings. Hours.	Percentage of wash-water.	Sulphate of Alumina. Grains per gallon. Per 24 hours.	8 hours ending: 8 A. M.	4 P. M.	12 P. M.	Parts per Million. Alkalinity. River water.	Alkalinity. Filt. water.	Turbidity. River water.	Turbidity. Filt. water.	Color. River water.	Color. Filt. water.	Bacteria per Cubic Centimeter. River. Average for 24 hours.	Filtered water. Average for 24 hours.	Hour of collection. 8 A. M.	4 P. M.	12 P. M.
1	11.22	2.5	1.13	1.13	1.13	1.13	20	13	12	0	27	5	1 100	32	27	42	27
2	11.36	2.4	1.11	1.12	1.10	1.10	20	13	10	1	27	8	900	37	25	50	....
3	10.98	2.7	1.13	1.13	1.13	1.13	21	13	10	0	27	7	1 700	21	....	21	22
4	9.38	3.4	1.12	1.12	1.13	1.11	21	13	11	0	28	7	1 500	18	21	20	14
5	10.05	2.5	1.12	1.12	1.12	1.11	22	14	11	0	26	5	1 800	22	30	17	18
6	8.39	3.3	1.08	1.13	1.09	1.01	22	14	10	0	26	4	2 100	17	14	20	....
7	12.31	2.5	0.83	1.01	0.75	0.72	23	17	10	0	26	5	1 400	130	....	140	130
8	10.85	3.0	0.79	0.74	0.76	0.86	23	17	13	1	26	7	2 800	160	200	180	100
9	9.35	2.9	0.94	1.01	0.91	0.90	19	12	18	0	27	5	4 600	200	110	240	275
10	10.00	2.9	1.00	1.06	0.97	0.97	18	11	14	0	28	6	4 000	120	....	100	150
11	11.31	3.1	0.92	0.97	0.95	0.86	19	13	13	0	25	6	1 800	130	150	95	160
12	9.72	3.1	0.95	0.90	0.91	1.03	19	13	15	1	28	8	1 700	120	120	170	70
13	8.65	3.2	1.12	1.14	1.09	1.14	20	12	15	0	27	6	1 700	85	75	120	60
14	8.52	3.2	1.26	1.05	1.27	1.45	20	12	19	0	29	6	3 200	41	47	55	21
15	9.74	2.7	1.61	1.76	1.54	1.54	15	6	18	0	28	5	5 000	13	18	13	7
16	8.09	3.4	1.45	1.47	1.43	1.46	13	4	16	0	28	5	5 700	14	11	23	8
17	10.41	2.6	1.32	1.41	1.27	1.27	14	5	16	0	28	3	4 100	12	4	17	15
18	10.68	2.8	1.23	1.32	1.26	1.10	14	6	15	0	26	3	2 400	20	19	8	24
19	9.11	2.9	1.09	1.07	1.10	1.09	15	7	13	0	26	4	1 700	21	....	23	19
20	11.55	2.4	0.98	1.10	0.91	0.92	17	10	11	0	26	4	1 300	35	20	24	60
21	11.65	2.4	0.95	0.98	0.99	0.88	18	11	9	0	26	6	1 000	65	80	41	75
22	10.01	2.9	0.88	0.89	0.87	0.89	19	13	9	0	26	6	750	62	42	43	100
23	8.61	2.7	0.88	0.90	0.88	0.87	23	17	9	0	28	6	800	43	40	48	40
24	8.69	3.3	0.89	0.89	0.87	0.91	24	18	8	0	27	6	900	55	37	80	55
25	6.86	4.1	0.91	0.93	0.89	0.92	25	19	6	0	27	6	1 700	70	46	85	90
26	9.99	2.7	0.88	0.87	0.87	0.91	26	20	4	0	26	5	1 300	75	70	65	90
27	8.95	3.1	0.88	0.85	0.89	0.91	27	21	6	0	27	7	750	55	70	60	29
28	7.86	3.5	0.88	0.90	0.87	0.88	27	21	8	0	25	5	800	39	32	46	....
29	7.80	3.6	0.91	0.94	0.91	0.88	28	22	9	0	27	5	1 300	22	22	....	....
30	7.33	3.9	1.01	0.88	0.99	1.14	29	22	12	0	26	6	900	34	....	26	42
Averages...	9.71	3.0	1.04	1.06	1.06	1.00	21	14	12	0	27	5	2 000	60	50	65	65

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TABLE No. 18—(*Continued*). DAILY SUMMARY OF LEADING AVERAGE RESULTS OF OPERATION.

Day, May, 1903.	Period between washings. Hours.	Percentage of wash-water.	Sulphate of Alumina. Grains per gallon.				Parts per Million.						Bacteria per Cubic Centimeter.				
				8 hours ending:			Alkalinity.		Turbidity.		Color.		River.	Filtered water.			
			Per 24 hours.	8 A. M.	4 P. M.	12 P. M.	River water.	Filt. water.	River water.	Filt. water.	River water.	Filt. water.	Average for 24 hours.	Average for 24 hours.	Hour of collection. 8 A. M.	4 P. M.	12 P. M.
1	7.08	4.0	1.20	1.14	1.28	1.18	30	22	12	0	28	4	1 000	13	10	23	6
2	6.71	4.4	1.15	1.17	1.14	1.13	31	23	10	0	28	6	1 200	13	11	14	15
3	7.60	3.1	1.14	1.16	1.13	1.12	33	25	9	0	29	6	1 200	14	17	18	8
4	7.76	4.0	1.13	1.12	1.14	1.14	34	26	10	0	29	5	1 200	11	10	15	9
5	6.31	4.0	1.15	1.15	1.14	1.17	34	26	9	0	27	4	1 500	12	11	8	17
6	7.94	2.7	1.17	1.16	1.19	1.16	34	26	10	0	29	4	1 100	11	11	12	10
7	6.76	4.1	1.23	1.22	1.25	1.22	35	27	13	0	26	4	1 100	11	8	10	15
8	7.66	3.6	1.23	1.22	1.27	1.20	35	27	14	0	26	4	1 600	13	14	13	12
9	9.20	4.0	1.10	1.23	1.23	0.86	36	28	16	0	25	4	1 400	15	10	13	23
10	7.98	3.6	0.93	0.90	0.94	0.94	37	30	16	0	26	5	1 600	55	29	14	120
11	7.96	3.5	0.91	0.88	0.94	0.91	38	32	13	0	26	6	1 300	16	...	10	23
12	9.82	2.8	0.93	0.92	0.93	0.95	39	33	12	0	26	6	900	19	31	16	9
13	7.81	3.3	0.93	0.96	0.90	0.92	38	31	10	0	27	6	900	12	13	6	18
14	10.52	2.5	0.94	0.95	0.93	0.94	39	33	11	0	26	5	700	15	22	9	14
15	12.02	2.2	0.94	0.94	0.94	0.93	41	34	11	0	26	5	800	23	8	28	32
16	10.17	3.2	0.96	0.97	0.97	0.93	39	33	13	1	26	7	900	33	60	32	16
17	9.85	2.8	0.93	0.94	0.92	0.92	41	35	17	1	27	7	800	25	30	15	29
18	7.81	3.8	1.16	0.92	1.26	1.26	42	35	18	2	26	9	900	80	140	80	22
19	13.78	2.6	1.12	1.24	1.24	0.88	43	35	15	1	27	9	1 100	18	12	21	22
20	8.71	3.2	0.93	0.88	0.91	0.99	46	39	13	0	26	8	800	27	35	28	18
21	7.92	3.6	0.99	0.99	1.02	0.96	45	37	14	1	28	10	3 000	60	15	...	110
22	9.19	3.0	1.09	1.00	1.10	1.19	46	38	16	1	27	9	3 400	60	130	43	12
23	10.16	3.1	1.28	1.28	1.28	1.28	47	38	14	0	27	7	1 300	26	30	26	22
24	9.99	2.3	1.21	1.22	1.19	1.21	46	37	14	0	26	7	1 100	28	38	26	20
25	9.70	2.6	1.22	1.18	1.24	1.23	48	39	14	0	27	6	900	15	22	18	6
26	7.45	3.5	1.20	1.23	1.24	1.13	47	38	13	0	28	6	1 000	21	9	15	38
27	7.51	3.5	1.09	1.13	0.99	1.15	47	39	13	0	28	7	1 300	38	42	46	26
28	8.32	3.2	1.14	1.12	1.13	1.16	46	38	14	0	27	6	1 200	23	31	24	13
29	7.48	3.4	0.93	1.01	0.90	0.89	49	42	15	0	27	6	1 400	31	46	22	25
30	8.71	3.5	0.98	0.93	1.00	1.02	48	42	14	0	27	7	1 800	41	26	41	55
31	8.62	2.8	0.88	0.89	0.88	0.87	49	43	12	0	26	5	1 100	26	38	21	19
Averages...	8.67	3.2	1.07	1.07	1.08	1.06	41	33	13	0	27	6	1 300	26	30	21	28

TABLE No. 18—(*Concluded*). DAILY SUMMARY OF LEADING AVERAGE RESULTS OF OPERATION.

Day, June, 1903.	Period between washings. Hours.	Percentage of washwater.	Sulphate of Alumina. Grains per gallon. Per 24 hours.	8 hours ending: 8 A. M.	4 P. M.	12 P. M.	Parts per Million. Alkalinity. River water.	Alkalinity. Filt. water.	Turbidity. River water.	Turbidity. Filt. water.	Color. River water.	Color. Filt. water.	Bacteria per Cubic Centimeter. River. Average for 24 hours.	Filtered water. Average for 24 hours.	Hour of collection. 8 A. M.	4 P. M.	12 P. M.
1	8.14	3.2	0.94	0.92	0.91	1.00	48	42	14	0	27	6	1 100	27	20	30	36
2	8.45	3.0	0.99	1.02	1.00	0.96	49	42	15	0	26	7	1 200	23	27	23	19
3	8.10	3.3	0.86	0.85	0.85	0.87	48	42	14	0	27	6	2 300	31	17	40	37
4	8.09	3.3	0.88	0.87	0.88	0.88	48	42	14	0	27	7	1 800	39	46	43	28
5	7.80	3.6	0.83	0.86	0.86	0.77	49	43	14	0	26	7	1 400	23	24	27	18
6	9.85	3.1	0.85	0.74	0.90	0.92	49	43	12	0	26	6	1 400	24	19	34	19
7	8.44	3.1	0.77	0.86	0.73	0.72	50	44	13	0	26	7	1 500	42	17	50	60
8	8.43	2.7	0.74	0.76	0.75	0.73	51	45	16	0	27	7	1 500	50	65	49	38
9	9.35	2.7	0.85	0.80	0.87	0.89	51	45	15	0	27	7	1 400	65	30	80	90
10	10.00	2.5	0.95	0.91	0.92	1.02	50	44	13	0	27	7	1 300	30	31	43	17
11	7.83	3.4	1.05	1.03	1.08	1.05	48	41	13	0	27	7	1 600	50	17	70	70
12	9.89	2.4	1.07	1.15	1.10	1.00	39	32	22	0	29	7	3 700	1 00	55	95	1 50
13	7.35	4.0	1.24	1.01	1.35	1.35	33	25	28	2	33	12	4 100	1 80	2 00	1 20	2 10
14	7.84	3.0	1.42	1.35	1.40	1.50	24	14	25	2	34	12	4 600	1 40	2 50	1 20	55
15	8.02	3.1	1.73	1.69	1.76	1.76	20	10	37	1	36	8	4 500	90	95	1 10	70
16	10.51	2.6	1.37	1.59	1.02	1.50	16	8	30	0	35	5	4 300	95	60	65	1 60
17	8.52	3.1	1.27	1.17	1.32	1 33	16	7	20	1	38	11	2 400	95	1 20	80	80
18	8.75	3.2	1.35	1.23	1.30	1.52	17	7	19	2	39	13	3 300	1 50	1 50	1 60	1 40
19	8.40	3.0	1.40	1.50	1.34	1.37	19	9	15	0	39	7	5 200	90	1 10	1 00	65
20	10.90	2.9	1.49	1.50	1.48	1.49	18	8	16	0	35	5	6 200	1 10	1 00	1 50	90
21	11.00	2.3	1.51	1.53	1.52	1.49	17	7	18	0	38	5	4 500	1 20	1 40	95	1 20
22	10.05	2.4	1.47	1.49	1.44	1.49	16	6	15	0	38	5	4 600	75	1 10	65	55
23	10.08	2.8	1.45	1.45	1.45	1.45	17	8	17	0	39	6	5 000	70	50	85	75
24	12.40	2.4	1.47	1.47	1.47	1.47	16	7	15	0	40	5	5 900	80	70	1 40	44
25	10.92	2.5	1.41	1.41	1.36	1.46	17	7	16	0	40	6	4 900	75	85	75	65
26	9.95	2.5	1.50	1.50	1.50	1.50	18	8	12	0	39	5	3 800	80	85	65	90
27	8.88	3.0	1.40	1.66	1.30	1.25	19	9	11	0	38	4	5 100	1 00	44	1 30	1 20
28	8.26	3.7	1.31	1.38	1.28	1.26	22	13	10	0	40	6	4 600	1 00	1 30	1 10	80
29	8.90	2.9	1.37	1.25	1.44	1.47	21	12	15	0	40	8	4 000	70	80	75	60
30	10.60	2.4	1.43	1.29	1.51	1.49	17	7	17	0	39	5	6 900	50	....	65	41
Averages	9.30	2.9	1.16	1.16	1.15	1.18	31	22	17	0	33	7	3 600	75	75	75	75

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The bacterial results obtained from the operation of a plant during its first ten months of service are hardly adequate for judging accurately its efficiency during a long term of years. Yet it is not without interest to compare such data, in the form of monthly average results from the filter plants at Lawrence and Albany, with those from the mechanical filter plant at Little Falls, all of which plants went into regular service during September, as shown in Table No. 19:

TABLE No. 19.

Month of first year of service.	Lawrence. Bacteria. Per cubic centimeter. River.	Lawrence. Bacteria. Per cubic centimeter. Effluent.	Lawrence. Percentage removed.	Albany. Bacteria. Per cubic centimeter. River.	Albany. Bacteria. Per cubic centimeter. Effluent.	Albany. Percentage removed.	Little Falls. Bacteria. Per cubic centimeter. River.	Little Falls. Bacteria. Per cubic centimeter. Effluent.	Little Falls. Percentage removed.
Sept.	.....	.....	.....	16 800	343	97.6	5 400	190	96.5
Oct.	16 500	560	96.6	10 700	142	98.6	3 800	90	97.6
Nov.	7 300	190	97.4	9 200	71	99.2	3 500	60	98.3
Dec.	9 800	200	98.0	45 800	213	99.4	5 800	50	99.1
Jan.	6 700	129	96.1	66 300	1 232	98.3	4 000	110	97.2
Feb.	8 000	244	96.9	119 000	938	99.2	3 600	70	98.1
March.	10 100	220	97.8	44 700	426	99.1	2 700	48	98.2
April.	11 500	230	98.0	26 000	80	99.6	2 000	60	97.0
May.	7 300	134	98.2	2 600	35	98.6	1 300	26	98.0
June.	6 080	110	98.4	3 100	45	98.4	3 600	75	97.9

During the four months which the Little Falls filters have been in operation, since the first of March, there have been four or five occasions when the coagulation was not fully adequate. The most noticeable instance, in early March, was due to disturbances in mechanical features, but the others came about in applying the solutions according to a prescribed schedule, which is considered to work well, on the whole, but which obviously is bound to be tuned up and improved somewhat as time goes on, just as is the case with any other kind of installation of this magnitude which is conscientiously managed.

It is well for those who seem inclined to view with little patience or charity the shortcomings of modern filtration works of this type, as they pass to the plane of practical excellence which science has proved them capable of reaching, to examine the detailed records of the analytical results from sand-filter plants, both in this country and abroad, and note that they, too, are not perfect devices, especially in winter weather and when the water applied to them is not properly prepared.

It appears to the writer that there is rather a pessimistic tone to the statement of Mr. LeConte when he says that the quantity of coag-

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ulant which the raw water in its various conditions calls for is "as variable as the winds." There is some variation, of course, it is true, if the plant is run economically and as is shown by the detailed records in the tables. But should people be disposed to pay for the coagulant on the basis that it is the quality of effluent which must be maintained without any regard to the cost of treatment, it is feasible to make the rate of application constant. Concerning the reference of Mr. Le Conte to the deficiency in the natural alkalinity of the river water, such as requires the addition of soda, those periods come only at times of severe freshets, and cover only a few days in a year. At such times this plant can be well handled with the aid of a moderate amount of common sense and technical skill, and involves no such complicated technico-chemical elaborations of procedure as Mr. Le Conte seems to have pictured in his mind.

It has been frequently and truly stated that the efficiency of mechanical filters can be very readily vitiated in part either by carelessness or viciousness on the part of the operator, particularly by failure to coagulate the applied water properly. On the other hand, it is not generally recognized that it is also true that it is not a difficult matter to throw a sand filter out of adjustment, or to by-pass it, should anyone, for a variety of reasons, be so disposed, although it is more of a proposition to manipulate viciously a sand filter than a mechanical filter. In the case of unfiltered waters which are of good appearance, although more or less polluted, it is hardly practicable quickly to detect faulty manipulation in the handling of a filter plant of either type without frequent and careful examinations of the plant, or by analyses, or both. With mechanical filters, dealing with waters which are either turbid or discolored by a vegetable stain, it is easy to detect a serious deterioration in the filtered water through the failure of its satisfactory appearance. In this way a filtered water, satisfactory as to freedom both from suspended mineral matter and dissolved vegetable stain, has its advantages, regardless of the desirability of having a "clean" water, to which Mr. Le Conte refers so disparagingly.

As to the question of the improvement of health, as regards water-borne diseases, in those towns and cities provided with filtered water, the experiences in Europe with sand-filter plants furnish a splendid testimony to the efficiency of that method of treatment under the given conditions. In most places in Europe from which data are available there is no feature in connection with the filter plants which is more conspicuous than the careful attention which they receive in their operation. In looking over the European experiences with sand filters, it is not to be forgotten, however, that there are some cases where sand filters have done poor work.

In this country, up to the present time, the introduction of filters,

regardless of the type, has not effected a reduction in water-borne diseases corresponding to that experienced with filters in Europe, generally speaking. There are a few filter plants of the mechanical type and a few of the sand-filter type, such as at Lawrence and Albany, which have been successful, generally speaking, in producing a good quality of filtered water, as judged by the typhoid fever statistics in the communities using the water. While, as is well known, in the majority of cases, mechanical filters have not been operated in a manner to produce uniformly good results, it is a fact, which does not seem to be appreciated by many, that the majority of the larger sand filters in this country that have been operated for several years have also failed to reach the goal which may be expected of them, as is noted by anyone who takes the trouble to examine carefully the typhoid fever experiences in cities which have sand filters, such as Poughkeepsie, Hudson, and Little Falls, N. Y., Ashland, Wis., Rock Island, Ill., etc. Mr. G. W. Fuller.

It is the writer's conclusion, after examining with care the general experience with filtration works in practice in this country, that the most urgent need now is that persons in charge of plants be educated to the responsibility which devolves upon them in operating such plants conscientiously and carefully, in order that good results may be obtained. American engineers can design and build good filters, but it can hardly be stated that any method of filtration will give thoroughly satisfactory results, and comparable to those obtained in so many places in Europe with sand filters, unless the operation is on a sound and satisfactory basis. The notion held by so many enthusiastic admirers of sand filters, that practical experience with them without exception has been satisfactory, and that a mechanical filter doing good work is either impossible or unheard of, is decidedly at variance with the facts.

At the Little Falls filter plant it is yet too early to speak very definitely of typhoid fever statistics as a measure of efficiency of the filters. In fact, it is quite likely that there will never be any notable change or reduction in the typhoid rate which can be explained by the filters, due to the general absence now of serious pollution in the raw river water and the wisdom of the officers of the Water Company in building filtration works before any epidemic resulted from the use of the water.

In Paterson (population in 1900, 105 000) there were thirty-four deaths from typhoid fever during the first ten months (September, 1902, to June, 1903, inclusive) that the city was supplied with filtered water. During the two preceding years, when raw water from Little Falls was supplied to the city, the typhoid deaths were twenty-five and twenty, respectively. Of the thirty-four deaths during the past ten months at least fourteen were due to infected well water or infected

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milk. Beginning on August 27th, 1902, some eight days before the filter was placed in service, an epidemic, due to an infected well in Paterson, broke out and continued for nearly two months, during which time one hundred and sixty-three cases were reported and fifteen of them were fatal. About three-fourths of these persons were known to have drunk the infected well water. From November 24th, 1902, to January 22d, 1903, there were reported one hundred and eleven cases of typhoid fever, and of these cases eleven were fatal. Careful inquiry showed that eighty-eight of the cases and four of the deaths were due to infected milk brought into the city from a certain creamery. Four of the persons who died of typhoid fever in Paterson during the ten months in question were found to have contracted the disease out of town.

In Passaic (population in 1900, 27 777) there were eleven and four deaths, respectively, during the two years that the city was supplied with raw water from Little Falls. During the past ten months, while receiving filtered water, there were no typhoid deaths in this city.

The foregoing information as to typhoid fever statistics is quoted by permission from the official reports of Dr. J. L. Leal, Sanitary Adviser to the East Jersey Water Company.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 955.

NOTE ON THE COEFFICIENT OF ELASTICITY OF CONCRETE AND MORTAR BEAMS DURING FLEXURE.

By Myron S. Falk, Jun. Am. Soc. C. E.

With Discussion by Messrs. E. J. McCaustland, W. K. Hatt, Gaetano Lanza and Myron S. Falk.

A correct knowledge of the value of the coefficient of elasticity in the case of the flexure of steel-concrete, concrete or mortar beams is a matter of the greatest importance in the designing of beams of this character. The following notes give the results for concrete and mortar beams tested to the point of failure, and are perhaps of more than ordinary value on account of the age of the beams tested.

These beams were square in cross-section, measuring approximately 4 ins. on each side, and were about 38 ins. long. They were first broken by weights applied at the center of 36-in. spans, and then each half of the broken beam was again broken by weights applied at the center of 16-in. spans. The beams were made, during the summer and fall of 1895, by Mr. Adolph Black, Instructor of Civil Engineering in Columbia University, and were tested by the writer, in the Mechanical Laboratory of that University, on an Emery testing machine, in November, 1902.

The beams were four in number. Two were of gravel-concrete and two of mortar. Table No. 1 shows the ratio of gravel and sand to

cement. The sand used was from Cow Bay, Long Island. It was sharp and clean, being entirely free from loam and organic matter. The gravel used was rounded, and varied in diameter from $\frac{1}{2}$ in. to $2\frac{1}{2}$ ins. It was well washed before being used. Three kinds of cement were used, as shown by the table. The usual cement tests showed that the cement was standard in quality. The material was watered to such a consistency that, when solidly rammed in the moulds, water flushed the surface slightly. The material was allowed to remain in the moulds for 3 days, and it set in the air; during the first year the bars were watered at intervals of 10 days or two weeks; during the second year they were watered at intervals of about two months, and after that very intermittently. The bars were never exposed to the weather, being kept during the entire time under cover, in the basement of one of the University buildings. The deflections during the test were measured by a lever deflectometer, reading, by means of a vernier, to the thousandth part of an inch. The instrument was examined for errors before and after the tests, and was found to be correct for the range of readings used.

TABLE NO. 1.

Bar.	Age, in years.	Span, in inches.	Section of Bar, in Inches.		Coefficient of elasticity, in pounds per square inch.	Extreme fiber stress, in pounds per square inch.
			Depth.	Width.		
A	7.4	36	4.12	4.05	.....	....
A_1	7.4	16	4.12	4.06	1 591 000	278
A_2	7.4	16	4.12	4.06	1 102 000	315
B	7	36	4.12	4.00	2 122 000	606
B_1	7	16	4.12	4.00	2 440 000	636
B_2	7	16	4.12	4.00	1 220 000	530
C	7	36	4.12	4.05	1 315 000	247
C_1	7	16	4.12	4.05	387 000	229
C_2	7	16	4.12	4.05	1 023 000	208
D	7.3	36	4.10	4.15	1 165 000	294
D_1	7.3	16	4.10	4.15	597 000	415
D_2	7.3	16	4.10	4.15	597 000	346

Bars A = 1 Aalborg cement, 2 sand and 4 gravel.
" B = 1 Atlas cement and 3 sand.
" C = 1 Alsen cement, 3 sand and 5 gravel.
" D = 1 Alsen cement and 2 sand.

The loads were applied at the intervals shown graphically on the diagrams. At different times the load was entirely removed in order that readings for the permanent deflections might be obtained. The readings were all taken about 15 seconds after the application or removal of the loads.

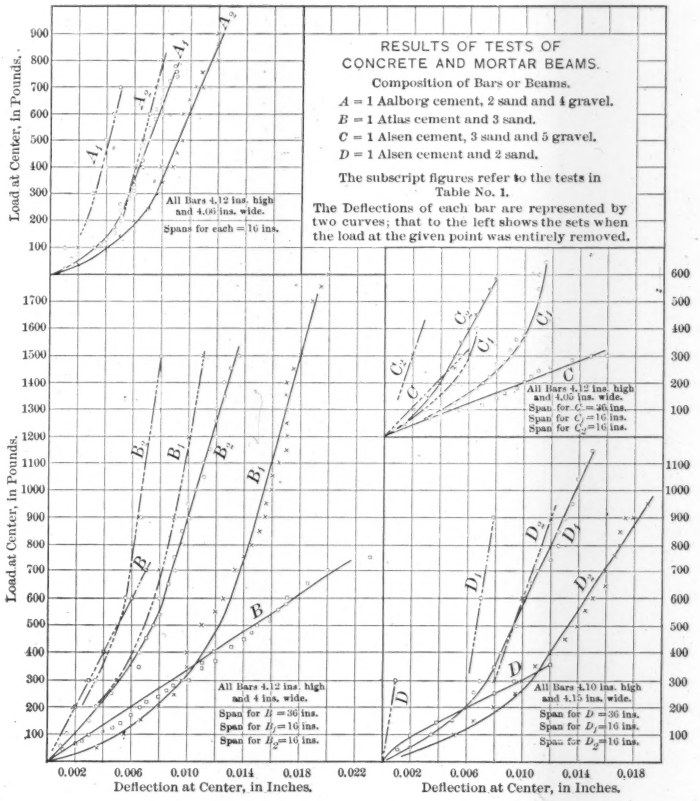
RESULTS OF TESTS OF
CONCRETE AND MORTAR BEAMS.
Composition of Bars or Beams.
A = 1 Aalborg cement, 2 sand and 4 gravel.
B = 1 Atlas cement and 3 sand.
C = 1 Alsen cement, 3 sand and 5 gravel.
D = 1 Alsen cement and 2 sand.
The subscript figures refer to the tests in Table No. 1.
The Deflections of each bar are represented by two curves; that to the left shows the sets when the load at the given point was entirely removed.
All Bars 4.12 ins. high and 4.06 ins. wide.
Spans for each = 16 ins.
All Bars 4.12 ins. high and 4.06 ins. wide.
Span for C = 36 ins.
Span for C1 = 16 ins.
Span for C2 = 16 ins.
All Bars 4.12 ins. high and 4 ins. wide.
Span for B = 36 ins.
Span for B1 = 16 ins.
Span for B2 = 16 ins.
All Bars 4.10 ins. high and 4.15 ins. wide.
Span for D = 36 ins.
Span for D1 = 16 ins.
Span for D2 = 16 ins.
Load at Center, in Pounds.
Deflection at Center, in Inches.

FIG. 1.

As shown by the diagrams, the strain of deflection consisted of two parts, one part apparently permanent and one part elastic, the latter disappearing upon the removal of the load. This is shown on the diagram for any one beam by the use of the same letter and subscript on two corresponding or mutually related curves.

The coefficient of elasticity was computed by using the difference between the two deflections thus found; in other words, the elastic deflection was used. This deflection was found to vary almost exactly as the center load, and could be represented by a straight line; no coefficient ef elasticity was computed for a center loading of less than 200 lbs.

The table also gives the values of the extreme fiber stress in the beam at the instant of rupture, the weight of the beam being allowed for in the computations. These values agree, with one or two exceptions, with the results obtained by other experimenters. An attempt was also made, using 4-in. cubes dressed from this material, to obtain a value for the coefficient of elasticity of concrete in compression. The blocks, however, were too small to permit of readings being taken directly from the sides of the specimen, and it was found that there was too much lost motion to permit of measurements being taken between the heads of the testing machine. The attempt to find these values was therefore abandoned. The ultimate resistance to compression of these cubes, when tested with plaster of paris beds, varied from 2 500 to 4 000 lbs. per square inch.

DISCUSSION.

E. J. McCaustland, Assoc. M. Am. Soc. C. E. (by letter).—It is quite evident, from a study of the tests on concrete and mortar beams reported by Mr. Falk, that, in so far as they prove anything, they prove that the coefficient of elasticity of concrete or mortar does not increase materially with age. However well established it may be that the strength of mortar made from Portland cement increases with the lapse of time, it is not established anywhere, as far as the writer is aware, that the coefficient of elasticity is affected in a like manner. For the practical purposes of the engineer, it is of more importance to know the properties and to be able to forecast the behavior of mortar and concrete during the earlier stages of the hardening process. This is the critical period, in many classes of work, when loads must be borne by the structure before time is given for an advanced degree of hardening. Nevertheless, all reliable information regarding this important structural material is worthy of record. Mr. McCaustland.

These tests are of interest, and afford valuable information, despite the fact that the varying mixtures give no opportunities for comparison, or for average results. This lack of comparison leaves many points unexplained. On the face of the record there seems to be no good reason why the beam D should show a fiber stress 24% lower than the beam B which contains the greater proportion of sand, and hence, theoretically at least, should be the weaker of the two. The extremely low coefficient of elasticity of the beam D, as determined by the tests on the half length, is also unaccounted for.

Beam A is not reported, as to the full-length test, but the different values of the coefficient of elasticity for A_1 and A_2 might be accounted for by slight errors in reading the deflections. The figures for fiber stress show close coincidence. With the beam B there is a wide variation in the coefficient of elasticity determined from tests on the two ends. Why the elasticity of B_1 should be 100% greater than that for B_2 is not clear. Beams C and D in all cases show lower values for the elasticity for the second tests, while the fiber stress does not differ widely from the value obtained in the first test.

The coefficient of elasticity is computed properly for the elastic deformation only, since the inclusion of the total deformation in any case would give a false idea of the properties of the material. However, the amount of this total deformation is a matter that should be taken into consideration, practically, since a mass of concrete under stress changes its character, more or less, during the earlier stages of the loading, and subsequent tests may show materially different results from the initial. The intrinsic properties of the mass do not change, but there is, no doubt, a rearrangement of the molecules and a redis-

Mr. McCaustland.

tribution of the initial stresses, which are due to hardening, which may leave the mass more compact and solid, but, whether stronger or weaker than before, depends upon the care taken in fabrication and ramming in the moulds, as well as upon the percentage of water used and the conditions attending the process of hardening. It may be of interest to compare the results with those obtained from neat-cement mortars of other brands, and hence the following data are presented.

Table No. 2 gives a record of results obtained by the writer from flexural tests of a number of neat-cement mortar beams made to determine the ultimate fiber stress and the coefficient of elasticity. The beams were approximately 28 ins. in length, and $2 \times 2\frac{3}{4}$ ins. in section. They were moulded in the spring of 1902 by Mr. H. B. Stevens, a student in the College of Civil Engineering of Cornell University, and were used in determining the time of initial and final set of mortar.

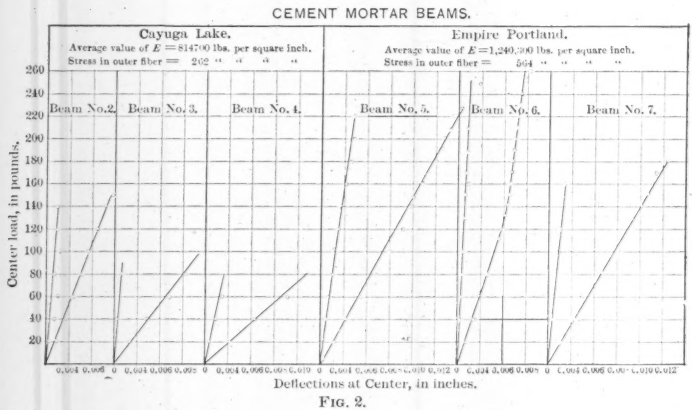

FIG. 2.

Briquettes of the same mortar were made, in order to test the effect of varying proportions of water on the tensile strength; but Mr. Stevens' investigations did not warrant any general conclusion. The beams, therefore, when tested, were about one year old, and had been kept, after hardening in air, in the College laboratory, at a temperature of about 65° Fahr. Four of the beams were of Cayuga Lake Cement, a brand manufactured near Ithaca, N. Y., and only quite recently placed on the market. The other three bars were of the well-known Empire Portland brand.

The span was uniformly 24 ins., and the load was applied at the center by increments of 20 lbs. Deflections were measured by a micrometer screw, reading to ten-thousandths of an inch. Readings were taken for the permanent deflections of the bars, after the application and subsequent removal of each successive load.

Mr. McCausland.

The diagrams on Fig. 2 show, as in Mr. Falk's experiments, the curves of permanent and elastic deflection; the intercept between these two curves at any load is the value taken for the deflection from which to compute the coefficient of elasticity. On Beams 2, 3 and 4 the value of *E*, the elasticity, was computed for central loads of 80 lbs., while for Beams 5, 6 and 7 the central load was 120 lbs.

TABLE No. 2.

Span=24 ins. Load at center. Age of beams=1 year.

No.	Brand.	Percentage of water in mixture.	Time of Set, in Minutes.		Section of Beam, in Inches.		Coefficient of elasticity, in pounds per square inch.	Extreme fiber stress, in pounds per square inch.
			Initial.	Final.	Width.	Depth.		
1	Cayuga Lake.	23	130	230	2	2.75	.....	571
2	" "	24	180	230	2	2.75	1 384 000	357
3	" "	25	180	235	2	2.75	600 000	238
4	" "	26	175	300	2	2.75	460 000	190
5	Empire Portland.	20	120	250	1.94	2.62	1 219 000	623
6	" "	30	235	360	2	2.75	1 582 000	618
7	" "	31.8	190	305	2	2.75	920 000	452

It is quite noticeable that the values of the coefficient of elasticity and the extreme fiber stress for the Empire Portland beams range fairly close to those recorded by Mr. Falk, although these are of neat-cement mortar instead of a mixture of 1:2 or 1:3. It is possible, but scarcely probable, that a greater age in these beams would have developed a greater strength and a greater degree of stiffness, with a consequent rise in the value of *E*.

It is submitted, however, that these tests, like many others reported in various papers, are altogether too few to warrant definite conclusions. The percentage of water used and the extreme fiber stress seem to vary inversely, but this is by no means an established relation, except possibly for certain extremes. There is here a field for a very definite and extended series of experiments with standard brands of American cement.

In addition to the preceding—not in the form of a discussion, but as new matter more or less related—the results of certain tests on concrete and mortar columns are here presented.

These columns were constructed by the writer in February and March, 1900, in the laboratories of the College of Civil Engineering at Cornell University, where they were tested, under the direction of Professor C. L. Crandall, M. Am. Soc. C. E., with Mr. O. A. Johannsen, Instructor in Civil Engineering, in direct charge of the work.

The cement used was Alpha brand, taken from a fresh supply provided for use in the cement laboratory work of the college. The usual

Mr. McCaustland.

tests did not show any abnormal qualities. The sand was a clean, fine, and not especially sharp, bank sand from Fall Creek. A careful test of the sand grains determined that the size of 60% of the total weight was less than 0.081 in., while 10% was less than 0.044 in. Adopting Hazen's method of recording sizes of filtering sands, the uniformity coefficient is 1.84. The stone used was sandstone, varying in size from ½ in. to 2 ins.

The columns were circular, 10 ins. in diameter and 40 ins. long, constructed in wooden forms made of narrow staves held together by yokes, which served the purpose of hoops. The cement and sand were mixed dry and the stone added. The least possible quantity of water was used, so that when the forms were rammed full, very little moisture appeared on the surface, and there was no quaking of the mass. The forms were removed after 24 hours, and the columns remained in the basement of the College building until tested.

The temperature of this basement did not vary at any time widely from 65° Fahr. The columns were watered at intervals of about four days until three months old, after which no water was applied. The tests were made on a Riehlé 400 000-lb. machine, and shortenings were read from micrometer rods placed between yokes held to the column by set-screws. Two rods, on opposite sides of the column, were provided, and contact was determined by an electric bell. At times the micrometers read widely different on opposite sides of a column, probably due to local weaknesses, but in all cases the mean of the readings was taken from which to determine the amount of shortening. The initial load was taken throughout as 1 000 lbs., which gave a unit stress of 12½ lbs. per square inch. On all columns, except Nos. 2, 4 and 5, the loadings were repeated five times before advancing to higher values, the micrometers being read at each application and release.

The diagrams on Fig. 3 show the stress and strain curves under the first loadings and also after a repetition of the loads, together with the permanent-set curves for the same conditions. The coefficient of elasticity is computed for the elastic deformation at 500 lbs. per square inch, except for the three mortar columns, Nos. 17, 18 and 19, which are computed at a load of 1 000 lbs. per square inch. The reason for the abnormal set shown in Column No. 3, with the accompanying high coefficient of elasticity, is not clear, and the mean value of E for the 1:2:3 mixtures is determined by using the values derived for Columns Nos. 1, 2 and 4 only. The 1:3:4 group gives fairly uniform results. The 1:3:5 mixture gives less uniform results, but is still within reasonable limits.

Owing to the slipping of the micrometers on Column No. 10, the stress and strain diagram for this specimen could not be plotted. This was true, also, of Column No. 16, of the 1:2:5 group. Column No. 13 gives an unusually low, as No. 14 gives a high, value of E, but

Mr. McCaustland.

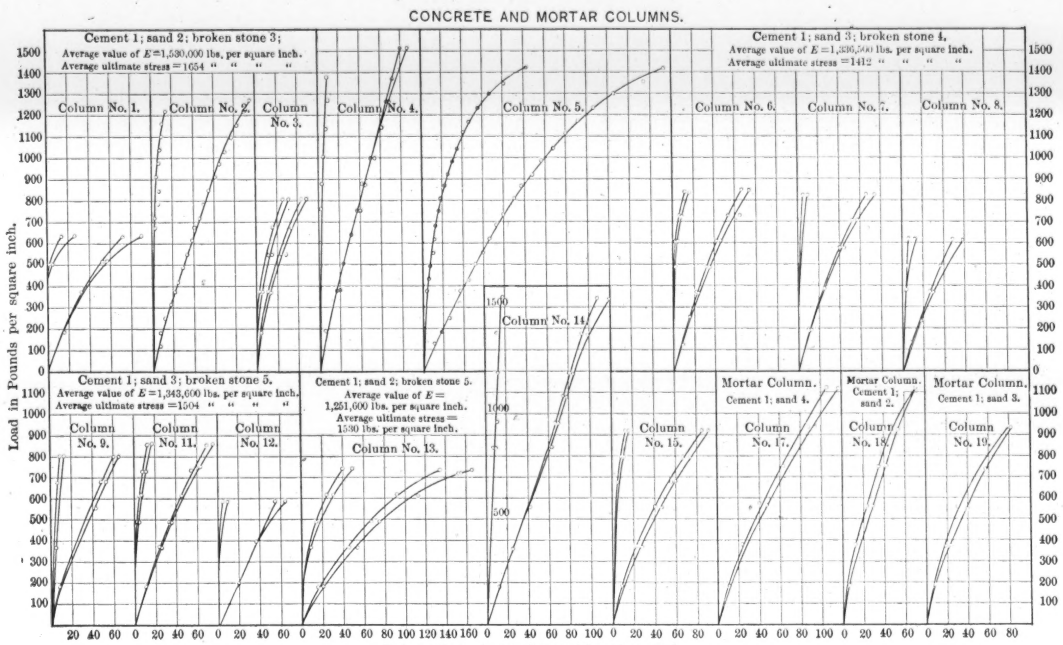

FIG. 3.

Mr. McCausland.

these wide ranges of value are almost certain to develop in tests upon low concrete specimens in which the aggregate bears such a large proportion to the total volume. Where the matrix (cement and sand mortar) is but slightly in excess of the volume of voids in the aggregate, it is almost impossible to get a homogeneous mixture and to preserve the homogeneity of the mass while it is being placed in position and rammed. Segregation is bound to occur, with resulting abnormal qualities, as made evident by many tests.

TABLE No. 3.

Proportions.	No.	Age at test, in months.	Load at failure, in pounds.	Area, in square inches.	Ultimate unit stress, in pounds per square inch.	Coefficient of elasticity, at 500 lbs. per square inch.	Average unit stress on 6-in. cubes of the same material.
Cement 1, sand 2 and broken stone 3.	1	14	79 300	79.3	1 000	1 050 000	1 751
	2	11	143 000	81.7	1 752	1 530 000	
	3	13	98 300	80.8	1 215	3 060 000	
	4	14	212 000	79.3	2 650	2 010 000	
Cement 1, sand 3 and broken stone 4.	5	10	120 000	80.8	1 484	1 100 000	1 432
	6	11	114 000	82.5	1 382	1 380 000	
	7	14	98 000	79.3	1 230	1 425 000	
	8	11	126 600	81.5	1 550	1 441 000	
Cement 1, sand 3 and broken stone 5.	9	14	126 400	81.5	1 550	1 450 000	1 092
	10	14	120 000	80.0	1 500	Not determined ...	
	11	14	146 400	81.5	1 792	1 531 000	
	12	14	90 000	76.8	1 170	1 050 000	
Cement 1, sand 2 and broken stone 5.	13	15	85 000	81.5	1 045	840 000	1 090
	14	15	180 000	83.5	1 955	1 510 000	
	15	14	118 300	81.8	1 450	1 372 500	
	16	23	137 000	81.0	1 680	Not determined.	
Cement 1, sand 4.	17	23	215 000	81.0	2 660	2 775 000	
Cement 1, sand 2.	18	23	273 230	81.0	3 410	4 625 000	2 895
Cement 1, sand 3.	19	23	180 000	81.0	2 250	3 700 000	1 861

The low unit stresses developed by the 6-in. cubes are no doubt due to the difficulty in moulding such a small block of fairly representative material. The writer believes that concrete cubes for crushing tests should never be less than 8 ins. on edge, and, preferably, 12 ins. There is a wide difference between the results obtained from crushing tests on 12-in. and on 6-in. cubes made from the same batch of concrete. Any form of test, on a concrete specimen, loses in value, unless the specimen can be assumed, without question, to be fairly representa-

tive in character. Hence, two general principles should govern in the preparation of the material for testing: Mr. McCaustland.

First.—Acquire and place on record a complete and comprehensive knowledge of every item which might determine or affect the physical or mechanical properties of the specimen. Character, composition, quality and form, as well as proportions and methods of fabrication, should form an important part of the history of a test specimen.

Second.—Keep in mind the practical limitations of commercial use, and avoid, if possible, the wide gaps which too often exist between laboratory results and those which may reasonably be expected in the field of "first-class work."

W. K. Hatt, Assoc. M. Am. Soc. C. E. (by letter).—The coefficient of elasticity used ordinarily by the designer of steel-concrete beams is that for direct tension or compression. It does not seem that the moduli given by Mr. Falk are of value for this purpose. Mr. Hatt.

Assuming, however, that the results desired by the author are useful, it appears that the details of the method of measuring deflections by means of a lever deflectometer should have been related. If this lever was placed directly under the beam, the amount of compression at the supports must have influenced the character of the curves shown in Fig. 1. Especially, in the case of the shorter beams, is it true that the deflections are probably due to compression at the support, shear of the beam, and bending of the beam. The ratio of height to span of only 1 to 4 in the case of the half beams is too small to yield proper values of the coefficient of elasticity in bending.

The author does not describe the method of calculation used to determine the coefficient of elasticity and the extreme fiber stress quoted in Table No. 1. If these are the result of the application of a formula that is based upon an assumption of a rectilinear relation between stress and strain and of equal moduli in tension and compression, it is the writer's opinion that the results of such computations are of little significance.

Gaetano Lanza, Esq. (by letter).—The following is written in order to present here whatever is now ready for publication regarding certain tests of reinforced concrete beams and columns made in the writer's laboratory of applied mechanics at the Masachusetts Institute of Technology. Mr. Lanza.

The specimens used by Mr. Falk were so diminutive in size, and so few in number, that they cannot be expected to furnish quantitative results that can be applied, with any confidence, to pieces of such sizes as are used in practice.

The pieces tested in the writer's laboratory, of which a partial account will be given here, were the following:

One plain concrete beam, 8 × 12 ins. × 11 ft. span.

Twenty-six reinforced concrete beams, 8 × 12 ins. × 11 ft. span.

Mr. Lanza.

Fourteen reinforced concrete columns, 8 × 8 ins., of which four were 6 ft. long, four were 12 ft. long, and six were 17 ft. long.

Seven reinforced concrete columns, 10 × 10 ins., of which two were 6 ft. long, four were 12 ft. long, and one was 17 ft. long.

Seven plain concrete columns, 8 × 8 ins., and 5 ft. long.

The composition of the concrete was the same in all cases, viz.: 1 part by volume of Portland cement (Star brand), 3 parts by volume of sharp, clean and coarse sand from Newburyport, Mass., 4 parts by volume of trap rock from Somerville, Mass., which would pass a 1-in. ring sieve, and 2 parts by volume of the same kind of rock which would pass a ½-in. ring sieve; these proportions being such as would a little more than fill the voids in each case.

The quantity of water used, varied from 6 to 7½% by weight.

The tensile strength of the steel reinforcing bars used, when plain, varied from 56 000 to 63 000 lbs. per square inch; and when twisted, the tensile strength was about one-third greater.

The reinforcing rods extended longitudinally throughout the length of the beams. Those in the lower part had the centers of their cross-sections at the ends, 2 ins. from the bottom, with a sag of from ⅛ to $\frac{3}{16}$ in. at the middle of the span, except in the cases of Beams Nos. 12, 13 and 14. The rods in the upper part, on the other hand, had the centers of their cross-sections 2 ins. from the top, with ⅛ in. rise at the middle of the span.

In Beams Nos. 12 and 13 the two reinforcing rods, in each case, were 2½ ins. from the bottom of the beams, and had from ⅜ to ½ in. sag. In these beams there were introduced on each side of the middle of the span eight pieces of ¼-in. twisted steel wire, bent in the form ⊔, enclosing the two reinforcing rods. In Beam No. 13 these ⊔-shaped wires were vertical, but in Beam No. 12 they were inclined at 45° with the horizon, sloping upward and away from the middle.

In Beam No. 14 the wire pieces were bent in the form of a square, which was placed vertically, and enclosed all four reinforcing rods.

Beams Nos. 26 and 27 each contained, in addition to their reinforcing rods, a vertical layer of expanded metal, extending throughout their length and height.

The tests of these five beams were made at the suggestion of L. C. Wason, Assoc. M. Am. Soc. C. E., for the purpose of studying the effect of these different arrangements upon the apparent tendency of the beams to break by longitudinal shearing.

Some of the columns were built with one reinforcing rod placed at the center of the section, and others with four rods placed, respectively, at the middle points of the four half diagonals of the section.

In the case of the 8 × 8-in. columns, the rods terminated ½ in. from

each end of the column, while, in the case of the 10 × 10-in. columns, the ends of the rods were flush with the ends of the columns. The beams were all cast in a horizontal, and the columns in a vertical, position. Mr. Lanza.

The quantities of cement, of sand, and of broken stone composing each batch were weighed in the case of all the columns and in the case of Beams Nos. 15 to 27, inclusive.

The columns were all tested in a horizontal testing machine, and, in every case, the compressions under successive loads were measured, those of the seven plain concrete columns serving to determine the modulus of elasticity of the concrete in compression.

In the case of the beams, longitudinal strains were measured at two different depths in the cross-section in the cases of Beams Nos. 3 to 14, inclusive, and at four different depths in the cases of Beams Nos. 15, 16, 17, 18, 19, 21, 22, 24, 25, 26 and 27.

The results of the measurements of strains will not be given here, but will be left for some time in the future.

A considerable number of the beams, and of the columns constructed, have not yet been tested, but will be at some later date, in order to determine the effect of greater age upon their strength.

The tables of results follow, with such explanations as may be needed to make them clear.

Before giving them, however, it must be stated, that the planning of the series, the work of testing, and figuring up the results, was performed, under the writer's direction, by the following gentlemen, for their graduating theses, viz.: Mr. Edward Seaver, '01, on beams; Messrs. G. M. Harris and G. B. Wood, '02, on columns; and Messrs. W. H. Adams and I. F. Atwood, '02, on beams. Moreover, these series of tests were rendered possible through the kindness of Mr. L. C. Wason, '91, President of the Aberthaw Construction Company, who furnished all the materials and built all the specimens.

In the case of beams, the manner of applying the load was as follows:

Beams Nos. 1 and 2.—Load at center; no strains measured.

Beams Nos. 4 to 11, Inclusive.—Load at two points, each 22 ins. from the middle of the span; deflections measured; also longitudinal strains in the portion between the points of application of the load, this being done as far as some load less than the breaking load. The load was then removed, and the beam was subsequently tested to destruction under a center load. The loads up to which strains were measured were as follows:

Beam No.	Load.	Beam No.	Load.
4.....	17 000 lbs.	8.....	13 000 lbs.
5.....	10 000 "	9.....	15 000 "
6.....	13 000 "	10.....	15 000 "
7.....	13 000 "	11.....	16 000 "

TABLE No. 4.—BEAMS.

Number of beam.	Age, in days.	Number, Size and Kind of Bars near Bottom. Number.	Side of square, inches.	Plain, P; or Twisted, T.	Number, Size and Kind of Bars near Top. Number.	Side of square, inches.	Plain, P; or Twisted, T.	Manner of loading at time of fracture.	Weight of beam, in pounds.	Breaking load, exclusive of weight of beam, in pounds.	Maximum bending moment at fracture, in inch-pounds.	Remarks.
1....	40	.....	.....	.....	.....	.....	.....	Center.	1 198	1 302	62 733	Vertical break near middle of span.
2....	40	1	¼	T.	.....	.....	.....	"	1 200	1 300	62 700	Vertical break at middle. Bar drew down to ⅛ in. and broke.
3....	39	1	⅜	T.	.....	.....	.....	At two points.	1 205	10 095	241 973	Vertical break at one point of application of load. Bar drew down to ¼ in. and broke.
4....	38	1	½	T.	.....	.....	.....	Center.	1 160	13 680	470 580	Concrete crushed on top.
5....	50	1	½	T.	.....	.....	.....	"	1 290	14 710	506 715	
6....	50	1	1	T.	.....	.....	.....	"	1 204	15 796	541 134	
7....	41	1	1¼	T.	.....	.....	.....	"	1 195	12 805	442 283	
8....	41	2	1	T.	.....	.....	.....	"	1 240	18 760	639 540	
9....	42	2	1¼	T.	.....	.....	.....	"	1 274	23 105	783 486	
10....	42	2	1¼	T.	1	½	T.	"	1 279	21 105	717 599	
11....	45	2	1¼	T.	2	½	T.	"	1 294	23 105	783 816	
12....	30	2	1¼	T.	.....	.....	.....	At two points.	1 282	24 200	553 553	
13....	31	2	1¼	T.	.....	.....	.....	" " "	1 292	29 200	663 718	
14....	30	2	1¼	T.	2	¾	T.	" " "	1 341	24 200	554 527	
15....	53	1	1	P.	.....	.....	.....	" " "	1 292	15 250	356 818	
16....	49	1	1	T.	.....	.....	.....	" " "	1 211	16 500	382 982	
17....	43	2	½	P.	.....	.....	.....	" " "	1 271	15 950	370 700	
18....	40	2	½	T.	.....	.....	.....	" " "	1 200	19 000	438 807	
19....	35	4	½	P.	.....	.....	.....	" " "	1 261	17 500	378 065	Beam had a crack about 18 ins. from center. Failed at this vertical crack.
20....	33	4	¼	T.	.....	.....	.....	" " "	1 213	20 000	433 329	Failed by longitudinal shearing.
21....	57	1	¼	P.	.....	.....	.....	" " "	1 213	12 500	295 015	Vertical break at one point of application of load. Rod pulled through. Concrete was not sufficiently packed in making.
22....	54	2	⅝	T.	.....	.....	.....	" " "	1 248	22 250	510 092	
23....	57	2	⅝	P.	.....	.....	.....	" " "	1 221	20 250	465 647	Beam cracked in handling, 22 ins. from center. Failed by longitudinal shearing.
24....	47	4	⅜	T.	.....	.....	.....	" " "	1 203	19 250	443 350	
25....	50	4	⅜	P.	.....	.....	.....	" " "	1 192	15 250	355 168	
26....	40	2	¾	T.	.....	.....	.....	" " "	1 215	24 250	553 548	
27....	49	1	1	T.	.....	.....	.....	" " "	1 222	21 750	498 688	

Mr. Lanza. All the fractures except Nos. 1, 2, 3, 4, 19, 20 and 21 were of the following general character: They consisted of a longitudinal shearing break at, or a little above, the reinforcing bar, and, in addition, a break extending diagonally (often at an inclination of about 45°) upward toward the center. The point where this diagonal break joined the top of the beam was sometimes at the point of application of the load, and sometimes near it.

TABLE No. 5.—REINFORCED COLUMNS.

Number.	Distinguishing mark.	Age, in days.	Area of section, in square inches.	Length, in feet.	Number of rods.	Side of square rod, in inches.	Plain, P, or, twisted T.	Actual breaking load, in pounds.	Value of P in formula: $P = f(A_1 + rA_2)$*	Manner of failure.
1..	1	30	64	17	1	1	P.	107 000	125 000	Crushed at end.
2..	2	30	64	17	1	1	T.	127 000	125 000	Buckled first, then crushed at end.
3..	7	29	64	12	1	1	P.	100 000	125 000	Buckled first, then crushed at end.
4..	8	28	64	12	1	1	T.	126 000	125 000	Crushed at end. Poorly made. Crushed portion cut off; the rest bore 156 000 lbs. at 40 days.
5..	9	32	64	6	1	1	P.	138 000	125 000	Crushed at middle, then sheared off along the rod to the end.
6..	10	31	64	6	1	1	T.	133 000	125 000	Crushed at end.
7..	3	31	64	17	1	1¼	P.	136 000	132 000	Crushed at end, shearing obliquely.
8..	4	35	64	17	1	1¼	T.	154 000	132 000	Crushed at end, breaking off 3 ft.
9..	5	35	64	17	4	¾	P.	182 000	140 000	Crushed at end.
10..	6	34	64	17	4	¾	T.	167 000	140 000	Crushed at end; concrete rather poor and rough at that end.
11..	17	31	64	12	4	¾	T.	147 000	140 000	Crushed and split open at end.
12..	18	32	64	12	4	¾	P.	153 000	140 000	Crushed and split open at end.
13..	15	29	64	6	4	1	T.	158 000	162 000	Crushed and split open at end.
14..	16	31	64	6	4	1	P.	244 000	162 000	Crushed at end.
15..	25	35	100	17	1	1	P.	215 000	188 000	Broke off clean, for 3 or 4 ft., at end.
16..	26	35	100	6	1	1	P.	200 000	188 000	Sheared diagonally at end.
17..	42	45	100	6	1	1	T.	228 400	188 000	Sheared diagonally at end, and broke back for half the length.
18..	35	31	100	12	1	1¼	T.	262 000	194 500	Sheared diagonally near end.
19..	36	29	100	12	1	1¼	P.	257 000	194 500	Crushed at end.
20..	33	28	100	12	4	¾	T.	300 000*	203 000	Did not break: exceeded capacity of machine.
21..	34	29	100	12	4	¾	P.	274 000	203 000	Crushed at end. Wedge-shaped piece forced in between rods.

*This formula has been used more or less to compute the breaking load of such columns, the meanings of the letters being as follows:

f = crushing strength of concrete;

A_1 = area of section of concrete;

A_2 = area of section of steel;

$r = \frac{E_2}{E_1}$, where E_2 = modulus of elasticity of the steel, and E_1 = modulus of elasticity of the concrete.

The numerical value of the constants that have been used in computing the values in this column are the averages of this series of tests, viz.:

$E_2 = 28\,000\,000$ } therefore $r = 8.23$, $f = 1\,750$ lbs. per square inch.
$E_1 = 3\,400\,000$ }

The values of P have been computed in order that the reader may be enabled to compare them with the actual breaking loads.

Mr. Lanza. *Beams Nos. 3, 12, 13 and 14.*—Load at two points, each 22 ins. from the middle of the span; deflections measured; also longitudinal strains in the portion between the points of application of the load, this being done up to some load less than the breaking load. The load was then increased until fracture occurred. The loads up to which strains were measured, were as follows:

Beam No.	Load.	Beam No.	Load.
3.....	10 000 lbs.	13.....	24 200 lbs.
12.....	22 000 "	14.....	22 200 "

Beams Nos. 15 to 27, Inclusive.—Load applied at two points, 22 ins. from the middle of the span, throughout the test, as follows:

No. 15.— Deflection and strains up to 14 250 lbs.

No. 16.— Deflection and strains up to 12 250 lbs., load then removed.
Deflection and strains up to 16 250 lbs.

No. 17.— Deflection and strains up to 12 250 lbs., load then removed.
Deflection and strains up to 12 250 lbs., load then removed.
Deflection and strains up to 12 250 lbs., load then removed.
Deflection and strains up to 14 250 lbs.

No. 18.— Deflection and strains up to 3 250 lbs., load then removed.
Deflection and strains up to 17 250 lbs.

No. 19.— Deflection and strains up to 16 000 lbs.

No. 20.— Deflection only up to 10 000 lbs., load then removed.
Deflection only up to 18 000 lbs.

No. 21.— Deflection and strains up to 10 250 lbs.

No. 22.— Deflection and strains up to 12 250 lbs., load then removed.
Deflection and strains up to 12 250 lbs., load then removed.
Deflection and strains up to 12 250 lbs., load left on for 22 hours then removed.
Deflection and strains up to 20 250 lbs.

No. 23.— No measurements taken.

No. 24.— Deflection and strains up to 12 250 lbs., load then removed.
Deflection and strains up to 18 250 lbs.

No. 25.— Deflection and strains up to 5 250 lbs., load then removed.
Deflection and strains up to 14 250 lbs.

No. 26.— Deflection and strains up to 22 250 lbs.

No. 27.— Deflection and strains up to 12 250 lbs., load left on for 45 hours, then removed.
Deflection and strains up to 20 250 lbs.

Mr. Falk. MYRON S. FALK, Jun. Am. Soc. C. E. (by letter).—In preparing this paper, no attempt was made to prove that the values deduced from the experiments would be theoretically correct. Engineers are familiar with the theory of flexure, so that they need not be informed about its limitations of accuracy; although the common theory is based upon some assumed conditions, it provides formulas which, by the introduction of suitable numerical constants, are in daily use. Professor

Mr. Falk.

Hatt claims that the values of the numerical constants derived in this paper are of little significance, because they are deduced from the formula of that common theory of flexure which involves the assumption of a rectilinear relation between stress and strain, and of equal moduli in tension and compression.

Professor Hatt's objection may be well taken, from the viewpoint of the exact theorist, although the writer thinks himself justified in believing that, at the present state of investigation, there is just as much reason to believe the coefficients of elasticity equal and constant as unequal and variable. The tensile experiments to determine the coefficient of elasticity are neither sufficient in number nor satisfactory in character to determine either the value of the coefficient itself or the variation in its value, and the same holds true, to a less degree, in the case of the compressive coefficient; moreover, in the latter case, a considerable number of experiments made at the Watertown Arsenal have actually shown the relation between stress and strain to be rectilinear, even up to the breaking point, a relation existing in the case of such materials as iron or steel only up to the elastic limit.

However, waiving any objection to the actual values of the coefficients in the case of concrete, how can Professor Hatt reconcile his opinions to the determination of the ultimate fiber stress in a material in which the coefficients of elasticity for tension and compression are actually equal and constant. In the case of steel, for instance, which may perhaps be assumed as such a material, the relation between stress and strain, taken over the whole of any section of the beam, at the instant of rupture, is certainly far from being rectilinear; at this instant the curve representing the stress-strain relation is as complex as any that has yet been conceived for concrete. In spite of this fact, it still remains sound engineering practice to use the values of the ultimate fiber stress derived from the equations based upon the apparently faulty conditions assumed by the common theory of flexure, rather than upon those assumed by the strict theorist.

Professor Hatt rather inaptly notes that the coefficient of elasticity used ordinarily by the designer of beams is the value found from direct tension or compression; but, if these values are unequal and variable, what value is the designer to take?

As a matter of fact, the coefficient of elasticity for bending, as used by designers, is merely an empirical quantity determined by experiment; due to the theory from which its value is derived, its value approaches more or less closely the values of the coefficient of elasticity for tension and compression. If the theory of flexure were exact, and if the coefficients for tension and compression were equal, then the coefficient of elasticity for bending would actually be equal to the other coefficients. But since the theory of flexure is not exact, but is based on certain assumed conditions, actual experiments are needed to

Mr. Falk. supply the values of those empirical quantities found in the equations of flexure. This fact has been recognized in the cases of iron, wooden, and other beams; why should the theory now be questioned in the case of concrete ?

It may prove of interest, to illustrate the complexity of the simple equations of flexure, when they are influenced by the conditions set forth by the enthusiastic theorist.* The conditions to be inserted in the common theory of flexure are simply these:

1. The coefficients of elasticity for tension and compression are unequal;

2. The coefficients of elasticity for tension and compression are variable quantities.

The following system of notation will be used, and the treatment will be general in character, so that it will be applicable to any material, although the present discussion refers only to concrete:

Let E_t = coefficient of elasticity in tension;

E_c = coefficient of elasticity in compression;

p_t = unit tensile stress in the fibres of the material, distant z from the neutral axis;

p_c = unit compressive stress in the fibers of the material, distant z from the neutral axis;

k_t = stress in extreme fibers on the tension side of the beam;

k_c = stress in extreme fibers on the compression side of the beam;

h_t = the distance, at any section, from the neutral axis to the extreme tension fiber;

h_c = the distance, at any section, from the neutral axis to the extreme compression fiber;

u = strain per unit length of the fiber, distant z from the neutral axis.

If the coefficients of elasticity are not variable, then $E_t = \frac{p_t}{u}$, and $E_c = \frac{p_c}{u}$; however, under the present and assumed conditions, the relations are expressed perhaps most simply in the following way:

$$\left. \begin{aligned} E_t &= \frac{p^m{}_t}{u} \\ E_c &= \frac{p^n{}_c}{u} \end{aligned} \right\} \quad \ldots\ldots\ldots\ldots \quad (1)$$

* The writer is in receipt of a letter, dated March 18th, 1903, from Professor C. Bach, of Stuttgart, in which the latter also takes the stand that only those equations which involve no direct proportionality between stress and strain should be used. The mathematical treatment, here presented, is therefore made to follow closely that given in Professor Bach's book "Elasticität und Festigkeit," Edit. 1902. Pages 214 and following.

For an example of the ingenious use of these equations in the solving of a single experiment on cast iron in flexure, the reader is referred to pages 241–248 of the same book. In that experiment, in addition to the actual flexure test, prior tests were necessary in order to determine the values, and the variation in the values of the coefficients of elasticity of the iron, both in tension and compression, and also to determine the ultimate resistances of the iron, both in tension and compression.

where m and n are the proper exponents for the material under consideration. Mr. Falk.

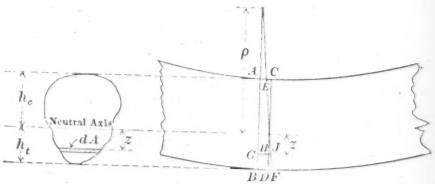

FIG. 4.

Fig. 4 illustrates a beam subjected to bending stress; $A\ B$ and $C\ D$ are two parallel sections of the beam, at an infinitesimal distance apart, and plane before and after flexure. After flexure, $C\ D$ (still remaining plane) assumes the position, $E\ F$. At any point, distant z from the neutral axis, such as G, for instance, the elementary length, $G\ H$, becomes distorted to $G\ J$; that is, the unit strain, u, at this point becomes

$$u = \frac{G\,J - G\,H}{G\,H} = \frac{G\,J}{G\,H} - 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

If ρ represents the radius of curvature, then, from similar triangles,

$$\frac{G\,J}{G\,H} = \frac{\rho + z}{\rho} = 1 + \frac{z}{\rho}.$$

By substitution, in Equation 2

$$u = \frac{z}{\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

By combining Equation 3 with Equation 1, then,

$$\left.\begin{aligned} u &= \frac{p^m{}_t}{E_t} = \frac{z}{\rho} \\ u &= \frac{p^n{}_c}{E_c} = \frac{z}{\rho} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The unit tensile and compressive stresses at any point, z, then become :

$$\left.\begin{aligned} p_t &= \left(\frac{E_t\, z}{\rho}\right)^{\frac{1}{m}} \\ p_c &= \left(\frac{E_c\, z}{\rho}\right)^{\frac{1}{n}} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

And the stresses in the fibers most remote from the neutral axis:

$$\left.\begin{aligned} k_t &= \left(\frac{E_t\, h_t}{\rho}\right)^{\frac{1}{m}} \\ k_c &= \left(\frac{E_c\, h_c}{\rho}\right)^{\frac{1}{n}} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Dividing the second of these equations by the first :

$$\frac{k^n{}_c}{k^m{}_t} = \frac{E_c\, h_c}{E_t\, h_t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Mr. Falk. and therefore

$$k_c = \left(\frac{E_c\, h_c}{E_t\, h_t}\right)^{\frac{1}{n}} k_t^{\frac{m}{n}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

In order to locate the neutral axis, the following condition, usual to the theory of flexure, must now be assumed : At any cross-section of the beam, the sum of the tensile stresses must equal the sum of the compressive stresses. If $d\,A$ represents the area of any elementary strip, distant z from the neutral axis, this condition is expressed algebraically as follows :

$$\int_o^{h_c} p_c\, d\,A = \int_o^{h_t} p_t\, d\,A \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

This equation may be simplified by means of the previous equations. Combining Equations 5 and 9,

$$\int_o^{h_c} \left(\frac{E_c\, z}{\rho}\right)^{\frac{1}{n}} d\,A - \int_o^{h_t} \left(\frac{E_t\, z}{\rho}\right)^{\frac{1}{m}} d\,A = 0$$

$$\left(\frac{E_c}{\rho}\right)^{\frac{1}{n}} \int_o^{h_c} z^{\frac{1}{n}}\, d\,A - \left(\frac{E_t}{\rho}\right)^{\frac{1}{m}} \int_o^{h_t} z^{\frac{1}{m}}\, d\,A = 0 \ldots\ldots\ldots (10)$$

Combining Equations 6 and 10

$$\frac{k_c}{h_c^{\frac{1}{n}}} \int_o^{h_c} z^{\frac{1}{n}}\, d\,A - \frac{k_t}{h_t^{\frac{1}{m}}} \int_o^{h_t} z^{\frac{1}{m}}\, d\,A = 0 \ldots\ldots\ldots (11)$$

This equation is used to determine the position of the neutral axis, which is distant h_c from the compression edge.

It is at once seen that h_c depends directly upon the stress, k_c, and is, consequently, also a function of the bending moment. The bending moment varies at different points along the length of the beam ; therefore the neutral axis must shift in position at different points along the beam, for any one fixed position of the loading.

Similarly, any change in the loading, either in amount or in position, changes the position of the neutral axis at any section.

This result is greatly different from that obtained in the simpler case of the common theory of flexure, where the neutral axis is always fixed in position throughout the entire length of the beam ; in that theory it always passes through the center of gravity of the section.

In order to determine the stresses in the beam, the external bending moment must be equated to the internal moment.

That is:

$$M = \int_o^{h_c} p_c\, z\, d\,A + \int_o^{h_t} p_t\, z\, d\,A \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

By substitution of the values of Equations 5, 6, and 8,

$$M = \left(\frac{E_c}{\rho}\right)^{\frac{1}{n}} \int_o^{h_c} z^{1+\frac{1}{n}}\, d\,A + \left(\frac{E_t}{\rho}\right)^{\frac{1}{m}} \int_o^{h_t} z^{1+\frac{1}{m}}\, d\,A$$

Mr. Falk.

$$= \frac{k_c}{h_c^{\frac{1}{n}}} \int_o^{h_c} z^{1+\frac{1}{n}} \, d\,A + \frac{k_t}{h_t^{\frac{1}{m}}} \int_o^{h_t} z^{1+\frac{1}{m}} \, d\,A$$

$$= \left(\frac{E_c}{E_t\, h_t}\right)^{\frac{1}{n}} k_t^{\frac{m}{n}} \int_o^{h_c} z^{1+\frac{1}{n}} \, d\,A + \frac{k_t}{h_t^{\frac{1}{m}}} \int_o^{h_t} z^{1+\frac{1}{m}} \, d\,A \ldots\ldots (13)$$

If $E_c = E_t = E$; and if $m = n = 1$, as in the usual case of the common theory of flexure, then :

$$M = \frac{k_t}{h_t}\left[\int_o^{h_c} z^2 \, d\,A + \int_o^{h_t} z^2 \, d\,A\right] = \frac{K_t I}{d_t} \ldots\ldots (14)$$

Where I represents the moment of inertia of the section about its center of gravity.

The preceding equations are expressed in the most general form; they assume the following values in the case of beams of rectangular cross-section, of height, $h = h_c + h_t$, and breadth, b, such as were used in the experiments set forth in the paper.

Equation 11 becomes :

$$\frac{k_c}{h_c^{\frac{1}{n}}} \int_o^{h_c} z^{\frac{1}{n}} \, b\, d\, z - \frac{k_t}{h_t^{\frac{1}{m}}} \int_o^{h_t} z^{\frac{1}{m}} \, b\, dz = 0 \ldots\ldots\ldots (15)$$

By integration and cancellation :

$$\frac{k_c}{h_c^{\frac{1}{n}}} \frac{n}{n+1} h_c^{\frac{n+1}{n}} - \frac{k_t}{h_t^{\frac{1}{m}}} \frac{m}{m+1} h_t^{\frac{m+1}{m}} = 0 \ldots\ldots (16)$$

Substituting for k_c its value as determined by Equation 8, and solving for k_t, there will be obtained :

$$k_t = \left(\frac{E_t}{E_c}\right)^{\frac{1}{m-n}} \left[\frac{m\,(n+1)}{n\,(m+1)}\right]^{\frac{n}{m-n}} \left(\frac{h_t}{h_c}\right)^{\frac{n+1}{m-n}} \ldots\ldots\ldots (17)$$

From this equation, the ratio betwen h_t and h_c for the corresponding value of k_t becomes:

$$\frac{h_t}{h_c} = \left[k_t^{m-n} \left(\frac{E_c}{E_t}\right) \left\{\frac{n\,(m+1)}{m\,(n+1)}\right\}^n\right]^{\frac{1}{i+1}} \ldots\ldots\ldots\ldots (18)$$

By means of the following relations,

$$\frac{h_t}{h_c} + 1 = \frac{h_t + h_c}{h_c} = \frac{h}{h_c}, \text{ therefore } h_c = \frac{h}{\frac{h_t}{h_c} + 1},$$

and by the substitution of the proper values for the constants, E_c, E_t, m and n, Equation 18 will determine the position of the neutral axis for the assumed value of k_c. This equation shows clearly how the position of the neutral axis changes with every change in the stress.

Mr. Falk. The value of the resisting moment is obtained in a manner similar to the preceding.

In the case of the rectangular beam, Equation 13 becomes:

$$M = \left(\frac{E_c}{E_t\, h_t}\right)^{\frac{1}{n}} k_t^{\frac{m}{n}} \int_o^{h_c} z^{\frac{n+1}{n}}\, b\, d\, z + \frac{k_t}{h_t^{\frac{1}{m}}} \int_o^{h_t} z^{\frac{m+1}{m}}\, b\, d\, z,$$

and by integration

$$M = \left(\frac{E_c}{E_t\, h_t}\right)^{\frac{1}{n}} k_t^{\frac{m}{n}}\; b\; \frac{n}{2\,n+1}\; h_c^{\frac{2\,n+1}{n}} + \frac{k_t}{h_t^{\frac{1}{m}}}\; b\; \frac{m}{2\,m+1}\; h_t^{\frac{2\,m+1}{m}}$$

$$= k_t\, b \left\{ \left[\left(\frac{E_c}{E_t}\right)^{\frac{1}{n}} \left(\frac{h_c}{h_t}\right)^{\frac{1}{n}} k_t^{\frac{m-n}{n}}\; \frac{n}{2\,n+1}\; h_c^2 \right] + \frac{m}{2\,m+1}\, h_t^2 \right\} \ldots . (19)$$

By substituting the value of k_t, as found in Equation 17, the moment becomes:

$$M = \left(\frac{E_t}{E_c}\right)^{\frac{1}{m-n}} m \left[\frac{m\,(n+1)}{n\,(m+1)}\right]^{\frac{n}{m-n}} \left(\frac{h_t}{h_c}\right)^{\frac{n+1}{m-n}}$$

$$b \left\{ \frac{n+1}{(m+1)\,(2\,n+1)} \left(\frac{h_t}{h_c}\right) + \frac{1}{2\,m+1} \right\} h_t^2 \ldots . . (20)$$

This is the equation which determines, analytically, the value of the internal resisting moment. It must be remembered that one set of values of h_t and h_c corresponds to but one particular value of the stress in the extreme fiber; therefore, as the value of this stress varies, the neutral axis shifts in position, and the value of the internal resisting moment must be constantly recalculated by means of the cumbersome Equation 20.

These are the equations which Professor Hatt claims the writer should have used in calculating the results of his experiments. When involved with the fact that there is practically no knowledge concerning m and n, and that the values of E_t and E_c are not reliably determined, the impossibility of such an attempt is surely apparent. It must therefore be evident, that in the present state of concrete investigations, no other assumptions than those made by the writer could, with propriety, have been made to furnish values for practical use.

The results of Mr. McCaustland's work are corroborative of the values given in the paper, and, in that respect, confirm its results; in the latter's experiments attention should again be called to the constancy of the coefficient, for any one specimen, even up to the breaking point. Professor Lanza's experiments will undoubtedly prove of much value, when he shall have published in full the strains and deflections of his experiments, together with the conclusions at which he may arrive; at present, his experiments are hardly presented in enough detail to permit of the deduction of conclusions by any other than himself.

MEMOIRS OF DECEASED MEMBERS.

THOMAS CURTIS CLARKE,* Past-President, Am. Soc. C. E.

DIED JUNE 15TH, 1901.

Thomas Curtis Clarke, the youngest son of Samuel Clarke, of Boston, Massachusetts, was born on September 5th, 1827, in Newton, Massachusetts. It is a tradition that his earliest known ancestor, Thomas Clarke, of Plymouth, came over in the *Mayflower*, as Mate. If so, he went back to England in that vessel, for he arrived the next year as passenger in the *Anne* and settled in Plymouth. He was a man of some note, and several of his personal belongings are to be seen among the relics preserved in Forefathers Hall in that town. Mr. Clarke's grandfather, Major Samuel Clarke, of Boston, married Martha, daughter of Obadiah and Martha Curtis, members of a prominent Boston family. Mr. Clarke's father was a man of varied talents, both scientific and artistic, and his mother was a daughter of General William Hull, of Revolutionary fame, and a first cousin of Commodore Isaac Hull, commander of the frigate *Constitution* (Old Ironsides) when she destroyed the English frigate *Guerriere*.

Mr. Clarke had four brothers and one sister, the best known of them being the Reverend James Freeman Clarke, a Unitarian preacher and author, named for his grandfather, the Reverend James Freeman, who married Martha (Curtis), the widow of Major Samuel Clarke. It was from such antecedents that Mr. Clarke inherited the literary and artistic tastes which characterized him, and which were second only to his engineering ability.

Mr. Clarke's early training was given by his grandmother, Mrs. Freeman, with whom he lived while a child. He says of her: "She taught me to read and to speak the truth." She may also have taught him his characteristic modesty and self-effacement. From 1841 to 1844 Mr. Clarke fitted for College at the Boston Latin School, under the famous Master, Francis Gardner. In the latter year he entered Harvard, and was graduated in the summer of 1848, on which occasion he officiated as class poet.

Mr. Clarke had intended to study the Law; but, being in delicate health at that time, he decided to adopt the profession of Civil Engineering. He obtained a position in the Engineering Corps of the Mobile and Ohio Railway, under Captain John Childe, the foremost

* Committee appointed by the Board of Direction to prepare this memoir: John F. O'Rourke, Adolphus Bonzano and Eliot C. Clarke.

railroad engineer of the day. Here he learned the practical work of railroad location, and here he remained until June, 1849, when a severe attack of fever compelled him to return to Boston. During that fall, while waiting for another position, he studied architecture, in the office of E. C. Cabot, of Boston, gaining knowledge of that profession, and of mechanical drawing, that was of service to him later. At that time there were few schools of engineering, and young engineers had to obtain their technical education as best they could.

Early in 1850 he secured a position as draughtsman under Mr. Shanly, Resident Engineer of the Ogdensburg and Lake Champlain Railway. When the work with which he was connected was completed, he returned to the Mobile and Ohio Railway, and took charge of one of the parties locating that road. This work lasted until September, 1851, when Mr. Clarke went to St. Louis and afterward to Chicago, in which city his mother and two of his brothers were then living. While in Chicago he studied in the office of Edward Burling, an eminent architect of that city. At this time, at the request of William B. Ogden, a public-spirited citizen, Mr. Clarke made a design for a tunnel under the Chicago River.

In October, 1852, he accepted a position under Mr. Benedict, Chief Engineer of the Great Western Railway of Canada, as Resident Engineer of the Second Division, which extended from St. Catherines to Dundas and included much heavy work and the shops at Hamilton. His assistants were Amory Dexter, of Boston; Thomas Ridout, of Toronto, and Augustus Bacon, from the Ogdensburg and Lake Champlain Railway. It was here that Mr. Clarke gained his first experience in foundation work in which he was so successful afterward. After the completion and opening of the road, in 1853, Mr. Clarke went to Port Hope, Ontario, Canada, as Assistant Engineer, under Mr. Benedict, of the Port Hope and Peterboro Railway. This road was finished in 1856, when Mr. Clarke and Mr. George Tate, one of the engineers of the Grand Trunk Railway, took a lease of it and operated it as a private enterprise. In 1858 the directors of the railway broke their contract and took the road from Messrs. Clarke and Tate, who recovered damages after a suit lasting about a year.

In November, 1858, Mr. Clarke was put in charge of one of the three divisions of the Government Survey of the Ottawa River, his work covering French River, Lake Nipissing and the Mattawan. His experiences in the field during the severe Canadian winter were most interesting, and his work was done so well and so promptly that he was placed in charge of the entire survey. The thoroughness of his work is shown by the fact that twenty-five years later, when the Canadian Government improved the Ottawa River, they adopted Mr. Clarke's plans and his exact location for a lock and dams at Carillon, at the head of the Lake of Two Mountains.

In the fall of 1859, Mr. Clarke, in partnership with Ralph Jones and Edward Haycock, took a contract for building the two Government Departmental buildings at Ottawa. Among other materials needed were iron beams, and to purchase these Mr. Clarke visited England in March, 1860. There he made the acquaintance of many distinguished men; among others, William Fairbairn. He was abroad about two months, returning to Quebec on an Allan Line steamship. Sir Hugh Allan had been urged to start his ships from Galway instead of Mobile, in North Ireland, and he sent one of them to try the harbor. It was on her that Mr. Clarke sailed, and he thus was one of the few who ever sailed from that port, as the one trip demonstrated its unsuitableness. The Ottawa buildings were finished in 1866.

About the end of the same year Mr. Clarke was engaged to build a bridge over the Mississippi River at Quincy, Illinois, for the Chicago, Burlington and Quincy Railway. This was the first iron bridge built across that river, and the securing of stable foundations presented many difficulties. The entire bridge was completed in two years without employing any contractors except for furnishing the iron superstructure. This was removed later and a heavier one substituted, on account of the great increase in modern trainloads; but no change was needed in the old piers.

In the fall of 1868 Mr. Clarke moved to New York City, where he formed a partnership with Charles Kellogg for furnishing and building iron structures, under the name of the Phœnix Bridge Company. In the spring of 1870 he moved to Philadelphia, and formed a new firm under the name of Clarke, Reeves and Company. Mr. Clarke was the senior partner, and his associates were Samuel Reeves, John Griffen and Adolphus Bonzano, of Phœnixville, Pennsylvania. The firm of Clarke, Reeves and Company was one of the leading bridge builders of the United States, and, among other works, constructed the Girard Avenue Bridge, over the Schuylkill at Philadelphia, many railroad bridges in the United States and in Canada, the Kinzua Viaduct on the Erie Railway, and a large part of the Elevated Railway system in New York City.

Mr. Clarke severed his connection with this concern in 1883, and in the next year became one of the original members of the Union Bridge Company, with offices in New York. During his connection with this concern, it built the Hawksbury Bridge in Australia, (the contract for it being taken in competition with the whole world), and the Poughkeepsie Bridge over the Hudson River. In building both these bridges the foundation work was very difficult, and Mr. Clarke's great experience in such matters stood him in good stead.

Mr. Clarke retired from the Union Bridge Company late in 1887, and during the remainder of his life carried on a business as Consult-

ing Engineer. He also traveled much, and was prominent among the members of this Society when they visited Europe in 1889. He was consulted by Henry M. Whitney, of Boston, in regard to the elevated railways in that city, and also in connection with mining development work in Nova Scotia. He was Consulting Engineer for the City of New York in building the Third Avenue and the Willis Avenue Bridges, being responsible for the design and construction of them. These were his last works, and he died on June 15th, 1901, in New York City, after a brief illness.

Mr. Clarke was elected a Member of the American Society of Civil Engineers on March 18th, 1868, and a Fellow on May 20th, 1872. He served as a member of the Board of Direction for the year beginning November, 1878, and as Vice-President from November 2d, 1870, to November 1st, 1871. From January 15th, 1896, to January 20th, 1897, Mr. Clarke was President of the Society. He was a Member of the American Institute of Mining Engineers, the American Society of Mechanical Engineers, and of the American Philosophical Society of Philadelphia. He was one of the first of the American members of the British Institution of Civil Engineers, and received both the Telford Medal and Premium, they being awarded to him for a paper, written in 1878, on "The Design Generally of Iron Bridges of very Large Span for Railway Traffic."

Notwithstanding his modesty and retiring disposition, Mr. Clarke was very popular. He was a member of many clubs and associations in different parts of the country, and in New York City was a member of the Union, Century, Harvard, Manhattan, St. Andrew's Golf and other clubs. He contributed many professional papers to the various engineering societies to which he belonged. He wrote the article on "Engineering" for "The Progress of the Century," published in 1900, to which men eminent in other branches of knowledge also contributed articles.

In the *Minutes of Proceedings* of the British Institution of Civil Engineers, Sir Benjamin Baker writes thus:

"The death of my old friend Mr. Clarke will be sincerely lamented by many British engineers, for no one has done more than he to promote the cordial brotherly relationship which now happily exists between American and British engineers. It also severs one more link with the past, for Mr. Clarke's early experience with bridge building was in the days when there was hardly one point of resemblance between American and British wrought-iron bridges, the former being modeled after the type of the original timber-truss construction and the latter on that of the cast-iron shallow-girder system. Mr. Clarke sometimes said that he shuddered when he thought of some of his early bridges, with long, slender cast-iron posts, slight lateral bracing, and totally inadequate pin-connections, even the floor girders being of the latter type, instead of the heavily-riveted low-stressed type which he lived to see substituted in all American bridge-work, as he

also saw each country gradually introduce the good points of the other's practice, so that no vital difference now distinguishes European and American bridges."

Mr. Clarke's life and works illustrate the highest form of engineering ability, while his modesty and straightforward, lovable character won for him hosts of friends. His death removed one of the brilliant lights of the engineering profession.

WILLIAM DURFEE GELETTE, M. Am. Soc. C. E.*

DIED APRIL 27TH, 1902.

William Durfee Gelette was born in Fairhaven, Massachusetts, on March 1st, 1847, and received his education at the Massachusetts Institute of Technology, being a member of the Class of 1869.

After leaving college he was employed until 1875 on various engineering works in New England, including water supply, drainage, iron bridge construction and street improvements, under such masters as Clemens Herschel and J. Herbert Shedd.

In 1875 Mr. Gelette went to California and entered the employ of the Southern Pacific Railroad Company, with which company and its successors he remained, almost continuously, up to the time of his death. He was in charge of the construction of the Southern Pacific transcontinental line from the Colorado River, on the border of California, to the Pecos River, in Texas, a distance of nearly 1 000 miles. Later, he was in charge of the construction of many other lines for that company, and from 1883 to the time of his death he occupied the second place in the Engineering Department of the road.

Mr. Gelette's life was ideal from the standpoint of an engineer: Conscientious, hard working, tireless, he took up everything presented to him with the thorough method necessary to achieve the best results. These qualities made him the trusted lieutenant of those he served, and, combined with his sympathy and patience, earned for him the highest regard of his subordinates.

He was married in Boston in 1871, and his married life was a particularly happy one. His nature was domestic, and he enjoyed nothing more than his home and his family. His widow, a son and a daughter survive him.

In the early part of April, 1902, in the interests of his employers, he visited El Paso, Texas, and was taken ill. His conscientious regard for his work kept him at his post until it was complete, after which his strength barely permitted him to make the return trip to his home, in Oakland, California, where he quietly passed away a few days later.

He was elected a Member of the American Society of Civil Engineers on April 1st, 1885, and always took the greatest interest in its work.

* Memoir prepared by W. B. Storey, M. Am. Soc. C. E.

WATSON WELLMAN RICH,* M. Am. Soc. C. E.

DIED JANUARY 12TH, 1903.

Watson Wellman Rich was born at Dayton, New York, on March 9th, 1841.

During the past generation he was the best known civil engineer in the Northwest. He spent the major portion of his professional life in the country between the Great Lakes and the Dakota Plains, of which the twin cities of St. Paul and Minneapolis form the commercial center. He was prominent during the three most teeming decades of the marvelous growth and development of this Northwest, through his connection with three of its railroads. He had direct and responsible charge of the construction of some two thousand miles of railroad over that portion of our country.

Going to the northwest portion of Wisconsin shortly after the Civil War, from which he was discharged as Captain of Volunteers (having refused the command of a colored regiment because he deemed it inconsistent with the high sense of honor held in choice army circles to enter that branch of the service), with previous liberal education, after having spent about two years in the service of various railroads and of the United States Engineer Department as Assistant Engineer, he became identified with the Wisconsin Central Railroad in July, 1870. During the next eight years he was busily engaged in constructing and operating this railroad, through the then almost unbroken forests, over the deep ravines and steep slopes of that difficult country, the south water-shed of Lake Superior, and often in half conflict with its then rough inhabitants.

From 1879 to 1883 he was Chief Engineer of the Minneapolis and St. Louis Railway, building five or six hundred miles of road in Minnesota and Iowa.

All his life he was consulted about enterprises, and he frequently examined and reported on them. In this respect he occupied the highest position in the Northwest.

From 1883 to 1890 he was building the principal monument of his career in the construction of the Soo Line, extending from Minneapolis eastward, entirely across the timbered States of Wisconsin and Michigan to Sault Ste. Marie, and westward almost as far as the Dakota Plains. After building the Soo Line his health was not very good, for a couple of years, although he did a considerable amount of miscellaneous work. In 1892 he resumed construction on the Soo Line, putting through its Northwest extension to the International Boundary.

Mr. Rich was most expert and proficient in the use of wood in

* Memoir prepared by Samuel B. Fisher, Esq.

structures, especially in bridges. His designs and plans for Howe trusses were perhaps the best that have ever been used.

In 1897, ripe in age, rich in engineering experience, strong in character, he went to China. He went first with ex-Senator Washburn to examine the route of the proposed Hankow Railroad for the Brice syndicate. Arriving in China, the Government would not even let him look at it. After some time, however, the Government called for him and delegated him to examine the line, not for the syndicate, but for the Government. On this trip he was accompanied by about a regiment of men, proclamations were sent in advance, calls were made on the Viceroys, etc. There was great difficulty in infusing into the lethargic heels of this superfluous multitude an acceleration of movement proportional to a reconnoissance of six hundred miles of line within a specified time. Early in the progress of this reconnoissance he gave the leader and officer in charge of these auxiliary forces a very practical object lesson, as shown by the following incident related by himself: Proclamations had been sent ahead to hold a feast at a certain important town, which would have required going into camp about 2 P. M. Mr. Rich, deeming this incompatible with finishing the reconnoissance within the time agreed on with the Government, pushed on with his work, going into camp miles in advance. As the convoy had orders to let no harm befall him, they feared the consequences of disobedience, and came straggling into camp at all hours during the night. There was no further serious difficulty about delays, and this reconnoissance of six hundred miles, on the route which will in all probability be the principal trunk line of China, was completed on time. After having his report translated into Chinese he returned to America, only to go back again in a few months as Consulting Engineer for the Chinese Government, his field being the southern part of the great Chinese Empire. He soon buckled into work, and was engaged in building a coal road a thousand miles in the interior, with the use of Chinese labor and facilities, among which was making embankments with material carried in baskets on the backs of natives, when the Boxer uprising stopped the work.

Actual operations began again soon after the Boxers were suppressed, Mr. Rich's engineers being among the first to return to work. Although he did not again go to the far interior, because His Excellency Sheng required his presence and services in Shanghai, the interior coal road is nearing completion, having been continued in charge of S. L. McCalla, immediately under Mr. Rich's directions.

Since July, 1902, Mr. Rich was a moving spirit in that American enterprise, the Hankow-Canton Railway. In December, 1902, he was appointed Chief Engineer of Construction, of that company. Engrossed in these large affairs, he spent his vital energies in the midst of the novel problems connected with it, and although sustained to

the last by his strong will, he died on January 13th, 1903, in Shanghai, which was then his home.

During his intercourse with the ruling and merchant classes of the Chinese he formed a very great admiration for the integrity and other sterling qualities shown in their character, as well as a distrust of the tricky Japanese. In a marked degree, the Chinese gentlemen who knew him confided in him and expressed profound sorrow at his leaving this sphere of existence. Had he lived and remained in the Orient he would have been a strong force in remoulding, or at least modifying, the Chinese character, and conforming its enterprises, to as great an extent as that would have been possible, to lines of modern thought and action.

He was a most masterful man. "His backbone—as he himself expressed it one day—came up into his hat." His friends all know that his heart was bigger than his backbone. He was every inch a gentleman. Like all strong characters, he was forceful in his dislikes and in his few enmities, as well as in his friendships. With his ever welling-up sense of humor and his genial disposition, he was the most delightful of companions.

Connected all his life with projects for the development of the country, in which large fortunes were made, he never tried to reap personal enrichment from them, but devoted all his time and energy to the interests of his employers. He died a man of small financial means, but rich in good will toward his fellows. He was never known to be envious, but always expressed the most unfeigned satisfaction at the success of his friends. His assistants and subordinates who were brought into close contact with his personality imbibed and ever after maintained feelings of trust and loyalty toward him. His good disposition toward others was contagious. All over the country are men, formerly associated with him, who bear in their hearts the salt of good intentions, infused into them from his ingenuous nature. Dominating all his other qualities, was a regal and ever-present sense of honor.

He was first a well-rounded man, in possession of all his faculties, and afterward a civil engineer. He might have followed almost any other avocation successfully had he devoted his capacity to it. While his work in America was, in a sense, completed, his departure leaves a void in the circles of his friends and engineering associates which can never be filled. It may be truthfully said of him, as it was said of one of old: "Know ye not that there is a prince and a great man fallen this day in Israel."

Mr. Rich was elected a Member of the American Society of Civil Engineers on September 5th, 1883.

JOSEPH MILLER WILSON, M. Am. Soc. C. E.*

DIED NOVEMBER 24TH, 1902.

Joseph Miller Wilson was born at Phœnixville, Chester County, Pennsylvania, on June 20th, 1838. He was a son of William Hasell and Jane Miller Wilson. His father and his grandfather were well-known civil engineers in the United States, his father being an Honorary Member of the American Society of Civil Engineers, and for many years Chief Engineer of the Pennsylvania Railroad. Mr. Wilson's great-grandfather and great-great-grandfather were among the most prominent civil engineers of their time in Scotland.

After a thorough preparation in private schools, Mr. Wilson entered the Rensselaer Polytechnic Institute, of Troy, New York, and was graduated therefrom in 1858, with the degree of Civil Engineer; after which he took a two years' special course in analytical chemistry with Professor F. A. Genth, of Philadelphia.

In 1860 Mr. Wilson entered the service of the Pennsylvania Railroad as Assistant Engineer, and in 1863 became Resident Engineer of the Middle Division. In 1865 he became Principal Assistant Engineer, and, later, Engineer of Bridges and Buildings of the Pennsylvania Railroad, continuing in the service of this road until January 1st, 1886.

Among the various structures designed and built by Mr. Wilson during this period were the Susquehanna and Schuykill Bridges, the original Broad Street Station, the Baltimore and Potomac Station at Washington, the Main Exhibition Building and Machinery Hall of the Centennial Exhibition, and, later, the Drexel Building and the Drexel Institute.

In 1876 Mr. Wilson, with his brothers, organized the firm of Wilson Brothers and Company, Civil Engineers and Architects, and this firm has done a very large amount of detail and expert work. The bridges designed and erected by him comprise all those on the Pennsylvania Railroad for many years, and many on other roads, the number too great to mention in detail. His firm were engineers and architects for numerous stations, shops, etc., on various railroads: Shops of the Northern Central Railroad at Baltimore; the Alleghany Valley Railroad shops at Verona, Pennsylvania; stations and shops for the Ninth and Third Avenue lines of the New York Elevated Railroad; stations and shops for the New York, West Shore and Buffalo Railroad; and stations on the Lehigh Valley, New Jersey Central, and Philadelphia and Reading Railroads.

Mr. Wilson was Chairman of the Board of Expert Engineers on the Washington Aqueduct Tunnel and Reservoir, acting under a joint Commission of Congress, in 1888-89; was Chairman of the Board of

* Memoir prepared by Joseph M. Knap, M. Am. Soc. C. E.

Expert Engineers to examine and report on the railroad terminal and station question at Providence, Rhode Island, in 1888; was one of the expert engineers to make examinations and report on the condition of the elevated railroads in New York City. He was one of the experts on the designs for the approaches of the New York and Brooklyn Suspension Bridge, and also one of the expert engineers reporting to the Board of Rapid Transit Commissioners for the City of New York, in 1891. In more recent years he was the Consulting Engineer for the Philadelphia and Reading Railway Company, and had charge, for that company, of all work on the Pennsylvania Avenue Subway, in the City of Philadelphia. He was one of the engineers appointed to examine and report on the improvement of the water supply for the City of Philadelphia, in 1899, the work being now carried out in accordance with that report.

Mr. Wilson wrote many scientific and engineering papers, among them the "Mechanical," the "Scientific," and the "Historical" for the "Illustrated Catalogue of the International Exhibition of 1876." He also wrote historical papers on this exhibition for London *Engineering*. By special request, he wrote a paper, on "American Permanent Way," for the British Association. He also wrote a comprehensive paper,* "On Specifications for Strength of Iron Bridges," and a paper† entitled "The Philadelphia and Reading Terminal Railroad and Station in Philadelphia," for the American Society of Civil Engineers; a paper on Port Perry Bridge, for the Institution of Civil Engineers; and a paper‡ on "Schools," with particular reference to Trade Schools, especially those of France and England. He also wrote sundry papers for various scientific and engineering journals.

As an inventor, Mr. Wilson took out several patents: On bridge details, flushing tanks for sanitary purposes, etc., etc.

He held many positions of honor and responsibility, some of them being as follows: Member of the American Society of Civil Engineers; Member of the Institution of Civil Engineers; Fellow of the American Institute of Architects; Member of the Franklin Institute, of which he was Manager from 1868 to 1887, and President for ten years, 1887 to 1897; President of the Engineers' Club of Philadelphia for 1888; Member of the American Philosophical Society; Fellow of the American Association for the Advancement of Science; Member of the Century Association of New York City.

Mr. Wilson received the honorary degree of Master of Arts from the University of Pennsylvania in 1877. At the Centennial Exhibition of 1876, in Philadelphia, he received medals and awards for designs of bridges and buildings, and in 1878 he received the Telford Premium from the Institution of Civil Engineers.

* *Transactions*, Am. Soc. C. E., Vol. XV, pp. 389, 484; Vol. XVI, p. 38.
† *Transactions*, Am. Soc. C. E., Vol. XXXIV, p. 115.
‡ *Journal*, Franklin Institute, 1889-90.

He was married to Miss Sarah Pettit, daughter of Judge Thomas McKean Pettit, on May 24th, 1869. They had two children, Alice May and Mary Hasell Wilson.

Mr. Wilson died of heart disease, suddenly, in his office in Philadelphia, on November 24th, 1902, in his sixty-fifth year. He is survived by his wife and his daughter, Mrs. John T. Gibson, of New York City.

For some years Mr. Wilson was a member and vestryman of St. Stephens Church, in Philadelphia. In the words of a resolution passed by this vestry:

"Mr. Wilson was a man in whom the power and the beauty of the Christian religion conspicuously manifested themselves.* * * Confronted constantly with difficult problems, he knew no other standard of conduct than the example of Jesus and his own very delicate sense of honor. Just in all his relations, generous to a fault, truthful in word, pure in spirit, a loving husband, father, brother, and son—these moral virtues only added luster to the endowment of a naturally powerful mind, nor did his religious beliefs prove inimical to scientific attainments which placed him at the head of an exacting profession."

The foregoing gives but an outline of a very useful, honorable and well-rounded life. His was an exemplification of what great results a quiet, unostentatious, industrious life can accomplish in the scientific and industrial world, when accompanied by superior intelligence, a thorough education and a morality based upon strict religious principles.

The writer of this memoir would feel that he had not done the subject justice had he not, in closing, alluded briefly to the high moral purpose which actuated Mr. Wilson in all that he did; and to the religious faith and practice, which, from his early youth until the day of his death, were the controlling influences of his successful and happy life.

Mr. Wilson was elected a Member of the American Society of Civil Engineers on April 2d, 1873. He served as a Director from January 18th, 1888, to January 16th, 1889; and as Vice-President from January 17th, 1894, to January 15th, 1896.

HENRY LAWRENCE CLEVERDON, Assoc. M. Am. Soc. C. E.*

DIED AUGUST 27th, 1902.

Henry Lawrence Cleverdon, known to the members of his family and to his most intimate friends as "Lonnie," was born at Washington, D. C., on April 6th, 1869. At the age of fifteen his parents returned to their former home, Chagrin Falls, Ohio, 18 miles southeast of Cleveland, and here he completed his common school education, and was graduated from the high school in 1888.

Being naturally an energetic boy, with an extremely practical turn of mind, and having decided early upon his life's work, he utilized his vacations, while still in the high school, as best he could to advance himself in his chosen profession. During the summer of 1887 he worked as Chainman for Mr. J. F. Brown, a Cleveland surveyor, and from April, 1888, until September, 1889, as Rodman on the Lake Shore and Michigan Southern Railway. While engaged on the latter work he came to realize the importance and value of a better education, and resigned to enter the University of Michigan as a student in the Engineering Department.

College work was always hard work with him—the means to an end—and, although he mastered his various studies with credit to himself, he chafed under too much confinement and longed for active outdoor life.

From July, 1890, to January, 1891, he served as Instrumentman and Resident Engineer on the construction of the Akron and Chicago Junction Railway (Ohio), now the Baltimore and Ohio Railway, and returned to college as soon as the work was finished. During the construction of the Wilkes Barre and Eastern Railway, through the mountains of Eastern Pennsylvania, Mr. Cleverdon was employed as Locating or Resident Engineer, from the beginning to the completion of the work, and some of the most difficult construction was under his direct charge. He expected to return to college and be graduated with his class—the class of '93—but one job after another came and was completed in such rapid succession that there seemed to be no time for anything else, and at last he gave up all thoughts of trying to return.

He served as Rodman on topographical surveys for the Short Line Improvement Company (Pennsylvania) from January to June, 1894, and from August, 1894, until April, 1895, was Resident Engineer, in charge of construction of six miles of the Fort Plain and Richfield Springs Railway (New York); but, when the latter road was nearly ready for the track, work was suspended, and Mr. Cleverdon, together with the other members of the engineering corps, was defrauded out of

* Memoir prepared by George H. Fenkell, Assoc. M. Am. Soc. C. E.

several months' salary, an incident that made him much wiser, if somewhat poorer. That he was not afraid of hard work, is shown by his serving first as laborer and then as Foreman and Superintendent for a water-works contractor at Fort Plain, New York, during the summer of 1895. During the autumn and winter of 1895–6 he was employed as an engineer on street railways and suburban electric lines in and near Cleveland, Ohio, and was Engineer in charge of the construction of three miles of a brick-paved highway for the County of Cuyahoga, Ohio.

From September, 1896, to October, 1897, Mr. Cleverdon was Resident Engineer in charge of construction of six miles of the Lorain and Cleveland Electric Railway, one of the first electric roads in the Middle States to be constructed in accordance with the best steam-road practice. In June, 1898, he was Locating Engineer for the Rapid Railroad, on a proposed line from Detroit to the St. Clair Flats, Michigan; and from August to November, 1898, Assistant Engineer on the Chicago and West Michigan Railroad, principally in charge of masonry construction.

He began work as Resident Engineer on the Cleveland and Eastern Railroad in January, 1899, but resigned in March, 1899, and in April began work as Division Engineer in charge of construction on the Copper Range Railroad, in Northern Michigan. This work was finished in June, 1900, and he at once accepted the position of Chief Engineer of the St. Johns and St. Louis Electric Railroad, Michigan, under the direction of the Arnold Electric Power Station Company, of Chicago, and remained there until the road was completed, in February, 1902.

For the next three months he was Resident Engineer on the Cleveland Water-Works Tunnel, and resigned this position to become Deputy County Surveyor of Cuyahoga County, Ohio, in charge of all bridges in that county.

On June 16th, 1902, he was married to Miss Elsie L. Williams, of Glenville, Ohio, and they at once began housekeeping in their new home, on the shore of Lake Erie, about 14 miles west of Cleveland. It then seemed as if his happiness was complete—a home, a loving wife, and a permanent position were appreciated all the more after fifteen years of the most active kind of work.

On the morning of August 23d, 1902, he boarded a car going toward Cleveland and requested the conductor to let him off at a farm road crossing about two miles farther east, to enable him to inspect a county bridge located near the car line. For some reason not known, the car passed by the cross-road and finally came to a stop on a wooden trestle 50 ft. high, a trestle that Mr. Cleverdon had constructed in 1897 while Engineer in charge of the construction of this road—the Lorain and Cleveland. When the car stopped he swung off on to the trestle and began to walk away from the rear end of the car. The car started, but

he supposed it had resumed its journey and gave it no further attention. As a matter of fact, the car was backing up, and the first warning he had of the impending danger was when it struck him. He partly jumped and was partly knocked from the trestle, struck a cross-timber on his descent and then dropped to the ground. When picked up a few moments later, in a semi-conscious condition, both limbs were found to be broken between the knees and hips.

He was taken to St. John's Hospital in the same car that struck him, an operation performed, his wife and family summoned and everything possible done to allay his sufferings and improve his condition. He did not seem to rally, however, and on August 27th, 1902, ten weeks after his wedding day, he passed away. The funeral was held the next day at his old home, Chagrin Falls, Ohio.

Mr. Cleverdon was a noble-hearted man, true to his friends and beloved by them in return. Always active and energetic, he had a wide circle of friends, scattered from one end of the country to the other, who mourn his untimely death.

He is survived by his wife, by his parents, one sister and four brothers.

Mr. Cleverdon was elected an Associate Member of the American Society of Civil Engineers on March 1st, 1899.

ROBERT BLUM OLNEY, Assoc. M. Am. Soc. C. E.*

DIED MARCH 4TH, 1903.

Robert Blum Olney was born on September 20th, 1870, at Charleston, South Carolina. He was the son of Clarence C. and Louisa C. Olney, of Charleston.

From January to August, 1888, he was employed in the office of the Chief Engineer for the Savannah, Florida and Western Railroad (Plant System), and from September, 1888, to June, 1892, he attended Lehigh University, from which he was graduated as a Civil Engineer in June, 1892. At college he was painstaking, and always reliable and trustworthy in his work, and his scholarship was excellent. Professor Merriman states: "His thesis was entitled, 'Plans and Specifications for a Locomotive Round House,' I find the drawings made with great neatness and the subject well treated throughout."

After graduation he was engaged on the Ohio Extension of the Norfolk and Western Railroad, in work varying from reconnaissance to final estimate, locating, re-tracing and revising lines, construction and track laying. In 1893 he was employed making surveys in the Powhattan mines of the Pocahontas coal field. From January, 1894, to January, 1898, he held the position of Assistant City Engineer of Charleston, South Carolina. His work consisted of general municipal engineering and public improvements, pavements, drainage, etc., and the reconstruction of the sea wall at the Battery. He was also Principal Assistant Engineer on the construction of the separate system of sewers—the sewage being lifted by Shone ejectors. From May, 1895, to May 31st, 1901, he was Engineer and Superintendent in charge of the sewers, power-house and other details connected with the sewer plant.

In June, 1901, by leave of the Mayor of Charleston, at the request of The American Pipe Manufacturing Company, he resigned his position in charge of the Charleston sewerage works and accepted a position with the latter company. In that capacity, he made topographic and hydrographic surveys for the location of a projected new water supply on Goose Creek at Charleston, South Carolina. During the summer he was engaged on the plans for the new Charleston Water-Works, and in the fall of 1901 he made extensive topographic surveys in Westchester County, New York, connected with water-works systems controlled by The American Pipe Manufacturing Company. In the spring of 1902 he was placed in charge of construction of the separate system of sewerage and the disposal plant for Burlington, New Jersey, the contractors being The National Gas and Construction

* Memoir prepared by J. W. Ledoux, M. Am. Soc. C. E.

Company, allied to the American Pipe Manufacturing Company, the sub-contractor being George Pfeiffer, Jr., of Camden, New Jersey.

After the completion of this work he was placed in charge of the construction of Charleston's new water supply from Goose Creek, but, on account of his failing health, remained there but a short time. He then left for the Southwest, intending to locate in a favorable climate in New Mexico or Arizona, but stopped at San Antonio, Texas, where he died on March 4th, 1903. It is stated that he was walking on the streets, apparently in fair health, on the day of his death. His remains were brought from San Antonio to Charleston, South Carolina, his home, and placed in the family plot in the beautiful Magnolia Cemetery.

Mr. Olney was especially capable in his professional work. He was a man of high integrity, and had the respect of all who knew him. The first intimation of his failing health occurred in the winter of 1901–1902 when a New York physician, whom he consulted in reference to some slight ailment, told him that he had symptoms of tuberculosis. This appeared to prey on his mind, although, even up to the last, his health gave no evidence of breaking down.

Mr. Olney was elected a Junior of the American Society of Civil Engineers on January 3d, 1895; and an Associate Member on September 5th, 1900.

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